The Story of Mortar

Craft Documentation of Traditional Mortars in the Indian Sub-Continent

Neeta Das

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19th century lakhori bricks and stucco details, Lucknow

Dedicated to Padma Sri Dr. O. P. Agrawal
who nurtured my interest in material sciences
and with thanks to Willam Revie,
who taught me all about it.

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Acknowledgements

Construction and building materials were subjects I ploughed through most of my undergraduate studies. Luckily they did not surface during my post graduate studies in architectural history but my casual attitude towards these subjects started pinching when I entered the field of conservation which, I soon realised, had a deep connection with materials and technology.

I found in Dr. O.P. Agrawal, a chemist by training, and an expert in material conservation, a mentor who introduced and nurtured in me the love for scientific inquiry and analysis of art materials like paper, stone, textile, etc. I borrowed this knowledge and methodology and tried to examine with it building materials especially old bricks and stucco, stone and sand.

Soon my house became a museum of building materials collected from my many travels and site visits but I could not effectively analyse these materials for use in my practise. I was lucky to get an opportunity to train at the Scottish Lime Center in Scotland where I learnt how to study traditional materials and use that knowledge to conserve buildings. Prof. Niels Gutschow motivated me to explore funding options and also gave me a reference that helped me get a grant with Gerda Henkel Shifting

My journey has been, nearly three decades long, but exciting and fulfilling. Thanks are due to my family for bearing with my obsessive hunt and collections. Thanks are due to Khushi Shah and Keyur bhai Patel who have been a sounding board for my research. Thanks are also due to my office staff Biplab Mukherjee and Antara Ghosh, and many other interns and associates over the past thirty years, for helping me with the endless testing and reporting.

This project could not have been possible without the assistance of Dr. Rosie Llewelyn-Jones who taught me how to do archival research at the British Library and also hosting me for the period in London; the funding from INTACH, Kolkata Scottish Heritage Trust, and Gerda Henkel Stiftung, who also gave me a grace period of extra two years during the pandemic to complete this report; and thanks are due to Ishita Das for beautifully composing it together as a book and to Ramesh Bhole for painstakingly proof reading the final draft.

Last but not the least, I wish to thank William Revie who patiently and quietly helped me with my research by answering my endless queries, testing materials in his lab for free, reading through my reports, and never making me feel like an ignorant architect in a scientific lab!

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19th century terracotta tiles over brickwork, Murshidabad

Chapter 1:

Introduction

The fact that India has a vast number of heritage buildings which are in urgent need of conservation and repair is well known. Work on conservation of these buildings is also going on but most of this work is not up to the mark and reasons for failure are not always tangible. Working in the field of conservation for over three decades made us aware of three plausible reasons; lack of skilled craftsmen, lack of scientific knowledge, and lack of research in the field of restoration in India.

Traditional lime mortars in India are also of a mysterious nature and have been a source of great discussion among historians and conservation architects. C.W. Pasley in his Observations on Limes (1838) writes, "Captian Smith, in his notes to his translation of M. Vicat's Treatise states that the Natives of India mix the common lime with Jaghery water, that which is with a solution of a very small proportion of coarse sugar in water." He further continues that, "Captain Smith observes, that every Master Bricklayer has his own favourite recipe, but he considers the essential ingredients, in addition to lime and sand, to be albumen of the eggs and the oily matter of the clarified butter, for which oil is sometimes substituted." Other than these surkhi or brick powder, blood, animal hair, straw, bel, and other edible juices have been mentioned as additives. Thus, when one gets down to the restoration of buildings, there is no 'scientific' proportions and or specifications for why, how, and when these ingredients are to be used, with 'every Master Bricklayer (having) his own favourite recipe' making the job of restoring a building very difficult.

Material research for restoration is still a very nascent field in the Indian Sub Continent. Restoration is done mostly based on systems designed for new constructions and/or by employing local 'unskilled' craftsmen and methods which are often neither scientific nor understood by the architects and engineers. This often results in poor quality restoration work and many a times, failure. Since the process of construction is not fully known, there is little scope for correction and repair. Thus, there is an urgent need to understand old mortars and there proportioning to be able to produce an 'authentic' and 'compatible' mortar for restoration.

Findings of Earlier Research:

In the past we under took several research projects on the subject some of which were published[i]. All research was based on a western models and extant scholarship with some basic assumptions. The first being that lime was the main binder used in traditional Indian mortars. It was also assumed that the specifications given by the architects and engineers, based on the Indian Standard Codes, were followed on site, (although later we found most of them were not practical or could not be communicated to the workers on site due to a language and literacy barrier). The final assumption was that the materials used for preparation of restoration mortars were 'standardised' and of good quality. However, we found that all of the above assumptions to be invalid. Thus, the findings of the above research were unusual and non-conclusive and we had to continue on the subject.But the above research helped dispel certain long standing myths of the twentieth century restoration work. The main of them being:

1. It was assumed that most traditional mortars (and plasters) were lime and sand mortars. However,

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i They included Revival of traditional technology for the survival of heritage buildings, Indian Architect & builder, Mumbai (2016); Brick Temples of the Gupta Period, Context, New Delhi (2013); Deconstructing Sand as an Aggregate, Context, New Delhi (2015); and Understanding Traditional Mortars for Brick Structures in the Eastern Part of India, Journal of the Building Lime Forum, UK (2016).

almost all mortar samples exhibited the presence of clay as a major ingredient. So much so that, mortars (as opposed to plasters and renders) were sometimes made primarily from clay/ mud. Since the clay in the region under study, that is the northern belt of the Indian sub-continent, and the Gangetic plain, is of very high quality, traditionally this was a good and inexpensive use of a local material. But due to lack of knowledge, scientific understanding of the technology, and proper methods to duplicate such mortars, they are fast being replaced by a more expensive, and incompatible material and technology.

If cement was considered to be complete 'no no' for the restoration of buildings made with lime mortars, lime is equally damaging if restoring mud/clay mortars. One can see such restoration being done on historic buildings in Nepal and India. Equally problematic is the use of expensive, and sometimes inappropriate, imported materials and technologies for restoration when local materials and technologies are not documented and understood. For example, a building made in clay/mud from the local region, which was cheap and easily available, if restored with lime, which is not only an expensive material, as it is not locally available, also promotes the replacement of a traditional technology, thus aiding its extinction.

2. It was also assumed while writing specification for restoration mortars that the materials procured were of standard quality. However, the research exposed that the sands were being sourced directly from river beds, un-cleaned and ungraded, for use in the preparation of mortars. Building limes were almost always of poor quality and not tested for their purity and/or hydraulicity. This meant that improper proportions of binder and aggregates were being used. The Indian Standard Codes, like IS: 2250-1981, Code of Practise for Preparation and Use of Masonry Mortars, also did not supply the correct information. Thus, with no quality checks and no standards, it was not possible to do quality restoration.

We consulted several Indian Standard Codes for material testing and preparation of mortars but found several gaps in the information provided which made it difficult for us to carry out our research to a desired conclusion. Some information like details of curing of lime mortars, storage of building materials, slaking of lime, changes and variations due to climate conditions etc. were missing. Other Public Works Department publications and Central Public Works Department publications were referred for preparation of estimates and specifications, but none of the above could provide satisfactory answers.

3. Finally, it was found that almost no two traditional mortar samples tested were the same. They exhibited a great variety in terms of materials, proportions, and colour. Therefore, it is important to test mortar and plaster samples of as many buildings covering various periods and regions as possible to give a complete understanding of materials and methods used, and modified, over a period of time.

The British engineers who worked in India during the colonial period have documented many traditional sources and methods of construction. They did this in an attempt to understand the local technologies which could be used, cheaply and efficiently, to build their empire. But their writings show that they too were confused with the non-standardization in the field of construction in India. They thus went about to formulate standards, one of which I found while researching in the India Office Library in the Bengal Public Works Consultation Indices (1855 Z/P/628, Fort William, August Circular 1855, Circular No. 59). The papers within clearly discuss several mortars, with their ingredients and proportions, that soon replaced the traditional mortars. Thus the books and papers of that period will be very useful in getting a peek into the pre-colonial building construction. Since the British presence in India is the turning point and has paved the way for 'modernism' in India, their story may help bridge the past and present together, since they were instrumental in standardizing the building industry, much of which continues to be used even today.

Literature Review:

A preliminary literature review presents three types of publication giving information on traditional mortars and their replication for restoration in the Indian sub-continent. The first type includes writings by British traveler and engineers like C. W. Pasley, Observation on Limes (1838), which talks in detail about the variety in mortars and the organic additions like gur, bel, eggs, even blood. But why they are added and in what proportion is not mentioned. Recent studies based on this model have been done by Satish Chandra and published in History of Architecture and Ancient Building Materials in India (2003). Here material analysis has been included but the research fails to give a practical approach for their use in restoration.

The second set of writings are by historians like O.P. Jaggi, Dawn of Indian Technology (1969), Dharampal, Indian Science and Technology in the 18th Century (1983), and in the extensive works of Niels Gutschow, Rosie Llewellyn-Jones, Percy Brown among others, which add to the above scholarship but fall short of forming a scientific base for their use in restoration. A handful of technical works, which form the third type of writings, are done to document for restoration by United Nations Educational Scientific and Cultural organization like the study by Caterina Bonapace and Valerio Sestini, Traditional Materials and Construction technologies used in the Kathmandu Valley (2003), and Appropriate technologies in the conservation of cultural property (1981). But both include mortars as a small part of the study.

Much of course has been discussed and written about building lime in the western world. Books such as Small Scale Lime Burning (1985), by Michael Wingate and Lime and Lime Mortars (2005) by A.D. Cowper are extensively used for practical applications. Similar books have been published by the Indian National Trust for Art and Cultural Heritage example What are Lime Mortars (2006) by Gurmeet S. Rai and Paromita Desarkar. However, all the above books take building lime as the main binder and lime mortars to be the standard traditional mortar. Almost no work is done acknowledging the presence of clay or other binders in the field of restoration.

Recent studies on 'green buildings', 'sustainable architecture', etc. have given rise to much interest in the study and use of mud, clay, adobe, and mud blocks. Publications such as Building with Stabilized Mud (2007) by K.S. Jagadish have come into the market. They will be of immense help in the study of clay but none of them deal with the use of clay/ mud/other local and traditional materials in historic buildings. There is dire need to re-visit the study of traditional mortars and documentation of local building crafts, with the intention of developing appropriate restoration technologies for India.

Research Methodology:

A need is thus felt for the study of traditional technologies and revival of the traditional skills. Brick, stone, and mortar (as clay, lime, sand, surkhi, etc.) still remain the most important traditional construction materials and a knowledge of their use and production is very essential for restoration. The study has been done in three parts:

1. A chronological and historical study of traditional mortars from secondary sources to assess the variety and non-standard nature of mortars in the Indian sub-continent has been done.

2. Some local traditions of construction especially those of mortar making to identify traditional and current sources of building materials needed to prepare them have been studied. Great regional variations is found in the sub-continent and in India itself. Craft documentation of the northern alluvial plains has been carried out as a exemplar for this research.

3. An attempt has been made to develop a methodology for the preparation of restoration mortars in India which addresses the need of variety, quality, and compatibility with the 'original' mortars.

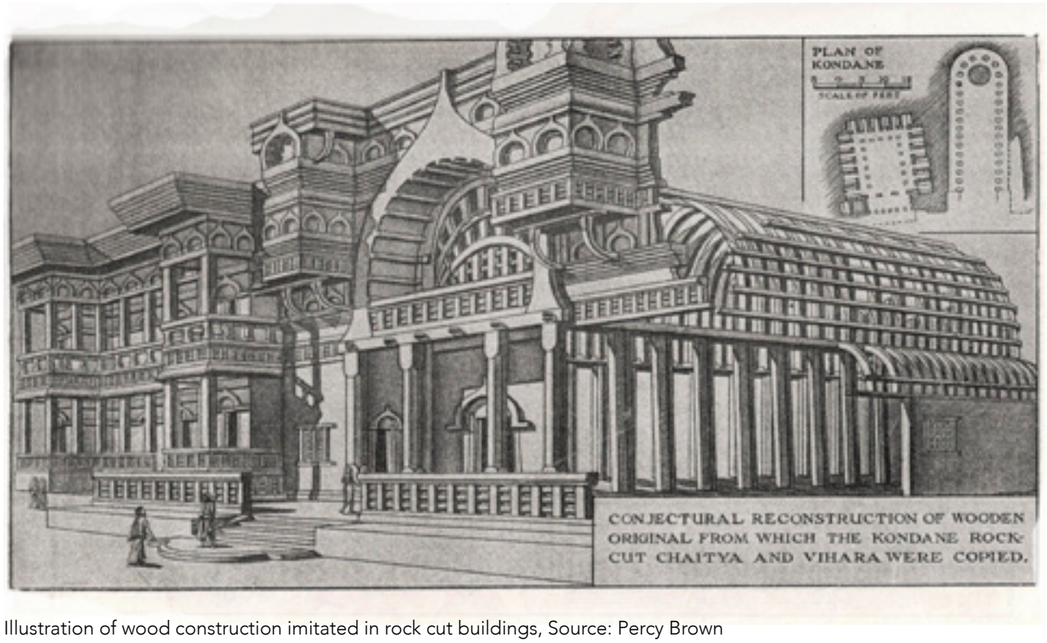
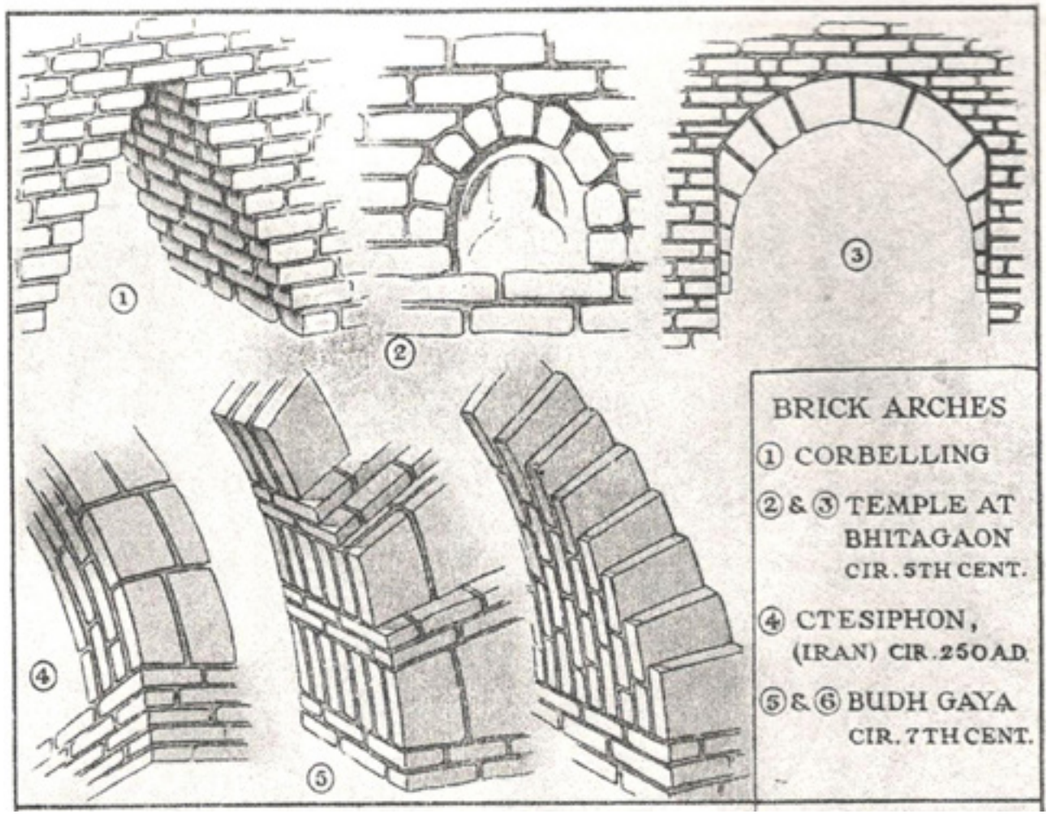

PLAN OF KONDANE
SCALE OF FEET
CONJECTURAL RECONSTRUCTION OF WOODEN ORIGINAL FROM WHICH THE KONDANE ROCK-CUT CHAITYA AND VIHARA WERE COPIED.

Illustration of wood construction imitated in rock cut buildings, Source: Percy Brown



Corbeled arches in early Hindu buildings

Chapter 2:

Historical background of Construction Mortars up to the 11th century AD

Introduction:

The use of cementing material dates back to 12000 BC in Israel when a natural combustion between limestone and oil shale formed a natural cement compound. Before cementing materials up to 15000 BC, bitumen and gypsum were other natural binders used by Babylonians and Assyrians for constructing their brick buildings. Egyptians, by 3000 BC, used much improved lime and gypsum plasters for constructing their pyramids. By around 4th to 5th century BC, the Greeks used lime, sand, and a type of pozzolana in their stone and brick construction. This information had been documented in detail by the Roman architect and engineer Marcus Vitruvius Pollio and published in his book De Architectura[i].

Vitruvius, in the first century AD, wrote about architecture in the times of Roman emperor Caesar Augustus and his works have been compiled in De Architectura, translated as The Ten Books on Architecture which continues to be relevant even today. He starts his dialogue poetically from the beginning of time:

The men of old were born like the wild beast, in woods, caves, and groves, and lived on savage fare…it was the discovery of fire that originally gave rise to the coming together of men…they..began in the first assembly to construct shelters…some made them of green boughs, others dug caves…and some made places of refuge out of mud and twigs….then, taking courage and looking forward from the stand point of higher ideas…they gave up huts and began to build houses with foundations, having brick or stone walls, and roofs of timber and tiles…I shall now treat, to the best of my ability, of the things which are suitable to be used in buildings, showing their qualities and their excellence.

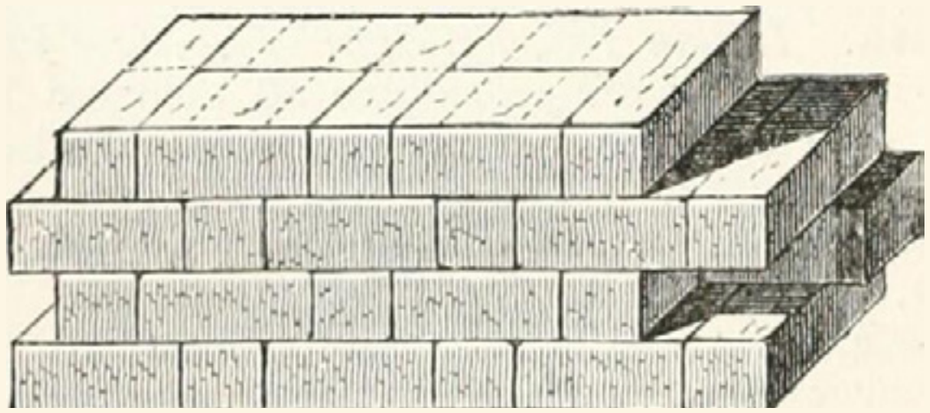
Vitruvius then elaborates on the major construction materials which include water, brick, sand, lime, pozzolana and stone. For all practical purposes, he has taken brick and stone as the major building blocks, lime as a binder, pit and river sand as aggregate, and pozzolana from 'natural sources' used for construction below water and for adding strength. A whole chapter is dedicated to timber which is to be used primarily as a roofing material.

One chapter, important for us here, elaborates on how these building materials are to be used in the construction of walls. Vitruvius here makes a study of local systems used in Rome and compares them with the systems used in Greek and makes a comparison between the two, pointing out the strengths and weaknesses of each. He writes there are two kinds of walls, opus reticulatum (net like work) and opus incertum (irregular work). Both wall types have a core of rubble 'puddled with the mortar, which is made of lime and sand'. Reticulatum has a structural brick veneer over rubble work, whereas in incertum the veneer is put directly over rubble work. This construction system, according to Vitruvius has a problem of 'bulging' and advices for best results that the Greek system be used, isodomum (when all the courses are of equal height) and pseudisodomum (when the rows of courses do not match but run unequal), where the dressed stone or ashlar, is laid in even or uneven courses to make walls. He also advised using brick instead of rubble, finished with highly polished stucco or stone. In the end he writes, 'as for wattle and daub I could wish that it had never been invented,' but goes on to give a brief description of the same[ii].

The earliest known phase of building construction in India, excavated in 1921, has been designated

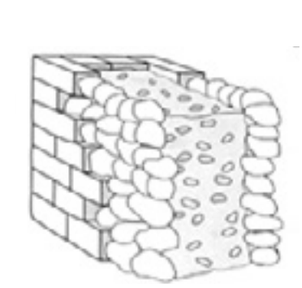
i Modena, Lourenco, Roca (eds). Structural Analysis of Historical Constructions. 2005. London: Taylor & Francis Group. (Kirca. O. Ancient binding materials, mortar, and concrete technology. page 87)

ii Morgan, Morris Hicky. (Tr.), Vitruvius: The Ten Books on Architecture. New York: Dover Publications, Inc. 1960.

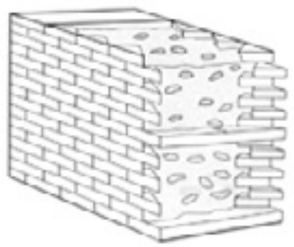


Opus Quadratum (shared brickwork)

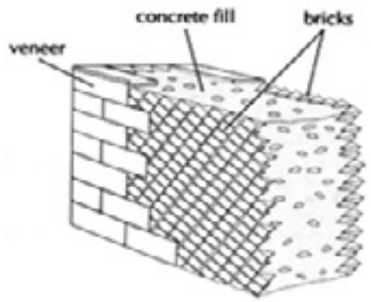
The Great Bath, Mohenjodaro (3000 BC to 2000 BC)



Opus Incertum
(Irregular work)



Opus Testaceum
(Formwork)



Opus Reticulalum
(Netlike work)

as the 'Indus Valley Civilisation.' It was in a fairly matured state as early as 3000 BC, around the same time as the Greek civilisation, but much later than Mesopotamia and Egypt. The two sites explored during this time were Mohenjo-daro (the Place of the Dead) in Sind and Harappa in Punjab. These are the earliest examples of cities and urban life in India with well designed and defined streets, drainage system, and houses and public buildings. In both cities the buildings were made entirely out of burnt brick, a little larger than the common bricks used today. They were laid in mud-mortar in what is known as English bond, where a course of stretchers alternating with a course of headers, care taken to break the joint where necessary. The buildings were largely two to three stories in height, with battered walls, and the upper stories largely made of wood. The roofs were flat and built of stout beams, covered with planking and finished with a top dressing of beaten earth. The civilisation declined some time in the second millennium BC due to some natural calamity[i].

Satish Chandra has documented this period in his book, History of Architecture and Ancient Building Materials in India Part1 & II[ii]. He writes that during the Harrapan period, fortifications and houses were made of mud bricks and set in mud mortar, however drains were made of baked bricks. Houses were also made of 'levitated' fine earth, plastered with the same earth, cow dung, and husk. Moulded mud bricks were also used and white and pink clay plasters have been mentioned. In Mohanjodaro, kiln fired bricks joined with red lime, probably kankar lime, and white lime is documented and bitumen was used for water proofing (pages 8 -18). No source of this information is mentioned in the book.

O.P. Jaggi in Dawn of Indian Technology (Volume 1) also writes that the excavated buildings of Mohenjo-daro were built of baked bricks laid in mud or mud and gypsum mortar[i]. Inner walls of the buildings were vertical and coated with thick mud mortar whereas the external walls were battered with a slope from above downwards. Platforms were built of unburnt bricks so that even they were submersed in water, there would be no rising dampness by capillary action. Foundations however, were built with crude burnt brick bats or burnt clay nodules. In the drain some lime plaster was found instead of gypsum. Floors were paved with mud, sun dried bricks, or burnt bricks, depending on use. Bricks were also used for door socket and corbeled arch and wood was used to span roofs and lintels (pages 69 -71). This author also does not give any source of this material.

The Vedic period, Buddhism, and Rock cut architecture (2000 BC to 200 AD):

After the decay of the Indus Valley Civilisation when the art of building comes again into focus, this no longer consists of well laid out cities of finished masonry, but takes a much more rudimentary form of huts and villages constructed of reeds and leaves. This period has been called the Vedic period and has been considered the bed rock of Indian society as most of the Vedas, Upanishads, and the Epics were written during this period. However, since the buildings of this period were made of perishable materials, the knowledge about these have been collected from the rock cut buildings hewn out during this period and life of the people of this time have been carved in bas-relief on the stupa railings of Barhut and Sanchi[ii].

The carvings indicate that people of the Vedic period lived in small fenced groupings and villages. The huts were of various shapes but initially they were circular resembling an inverted basket. At a later date the circular plan was elongated into an oval with a barrel roof. Towards the middle of the first millennium BC, the Vedic civilisation entered into the timber construction. Cities largely of wooden construction began to appear in various parts of the country,

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i Brown, Percy. Indian Architecture (Buddhist & Hindu). Mumbai: D. B. Taraporewala Sons & Co Pvt Ltd. 1997.

ii Chandra, Satish. History of Architecture and Ancient Building Material in India, Part 1&2, New Delhi, Text Books International, 2003.

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i Jaggi, O.P, Dawn of Indian Technology, Vol-I, Delhi, Atma Ram and Sons, 1969.

ii Brown

and according to Dhammapala, the great Buddhist commentator, they were planned by an architect by the name of Maha-Govinda. This is the first mention of an architect in the annals of India

Megasthenese, a Greek ambassador (who probably accompanied Alexander the Great) resided in the court of the Mauryan Emperor Chandragupta in around 300 BC in Pataliputra, today Patna, on the banks of the river Ganga, has left an account of the city and the royal palace which consisted of a hypostyle halls consisting of wooden pillars. Of this city nothing has survived except fragments of the wooden ramparts unearthed at Bulandi Bagh near Patna, of foundations which consisted of timbers laid in parallel lines like railway sleepers. To these horizontal beams upright posts were tenoned. Some Mauryan wooden remains are preserved in the Indian Museum at Kolkata. This method was used in other parts of the world as in Rome, as a scene on Trajan's Column depicts.

When Mauryan King Asoka ascended the throne in 274 BC and took the decisive step of making Buddhism as the state religion radical changes took place. It is during this time that the Ashokan School of Art and Architecture flourished. The state machinery was used to spread the teachings of the Buddha through permanent structures like rock edicts, monolithic stone pillars, shrines, stupas, and rock cut chambers. These structures were embellished with bas relief depicting the stories of Buddha and Buddhist sacred sites like Kapilvastu, Kusinagar, Uruvilva, and Rajgriha. These carvings give a detailed idea of the wooden architecture of the early Vedic period period. The high appraisement of the Mauryan artisan's skill of working in wood is also confirmed by their presence on the rock cut edicts. Timber construction details has been faithfully reproduced to embellish the rock cut spaces where no construction details were needed. Later these same wooden details were used for construction of stone railings in stupas and other Buddhist structures.

Citing secondary sources, Satish Chandra confirms that by the third century BCE, in the Maurayan period locally available stone was used in most cases. The Ashokan pillar was in local red Vindhyan sandstone whereas local marble was used in the Dharamrajika stupa, both are located in Sarnath. This also heralds the beginning of dry ashlar masonry, where no mortar was used for joining stone. During this period carved stone was used in abundance for decorative purposes. However, Mauryan bricks were used for monasteries and stupas foundations and core[i].

Buddhism and early Hindu buildings in Brick:

Moving into the common era (CE) almost all architecture produced in India was of Buddhist faith which had spread to the east, west, north, and south. Today most of these sites remain as mounds or archeological ruins, but investigations revealed that they were constructed entirely of bricks. The skilled handling indicates that it was a system of building which had been in practice for a long time. The bricks were large and strongly built and have been widely used, both in the alluvial plains, and other parts of the country where stone was in plenty, because of its easy handling and flexibility which offers greater constructional possibilities. Wood (timber) and stone beams have been used to span openings in doors, windows, and roofs. But the most common and unique system used was the corbelled arch which is achieved by overselling the courses till they meet at the top. The same system has been used in stone masonry, but is neither scientific nor stable. The stones used for this purpose were much larger in size as compared to the bricks today. (See table on the next page)[ii]. The decoration on these brick buildings has been mostly to produce relief ornamentation. For this purpose bricks were moulded, shaped, or chiseled in position, while in some instances they were carved in clay when in a 'green' state prior to burning. In addition to these methods which were used to produce repetitive designs, much of figure work was modelled in high relief in terracotta or stucco. As for the actual construction no specific system of bonding is observable, but the method of headers and stretches was allowed, care being taken that there were no continuous vertical joints. Between the joints a mixture of clay was used as a binder, but only as a thin layer, as the bricks were brought in close contact.

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i Satish Chandra (Pages 22-26)
ii, iii Brown

Lime mortar appears to have been known at this time, but was not commonly used[i].

Santosh Saran in History of Science and Technology During Gupta Period also is of the opinion that prior to the Gupta period, buildings were made of timber or other perishable material and dressed stone was first time appreciated during this period although the earliest temples were in bricks. Both bricks, in size and nature, and mortar were developed to high standards. Mortars were made of sand, clay, lime, and water with the clay of various types and colours. Plasters were sometimes made of mud and sand mixed with cow dung but was mostly lime mixed with sand. Lime was obtained from limestone and kankar, however, the proportion of the lime and sand varied[ii].

Location & Date	*Length*	*Width*	*Height*
Buddhist shrines, Ter, Sholapur (5th century CE)	17"	9"	3"
Bhitargaon temple, Kanpur (5th century CE)	17.5"	10"	3"
Temples, Sirpur 8th century CE)	17"	9"	3"
Temples, Ter, Sholapur (6-7th century CE)	16"	9"	2.5"
Common brick today	9"	4.5"	3"

Table of masonry sizes used in construction

Hindu Period and the evolution of temples (400 CE to 11th century AD):

By 400 CE, the Gupta dynasty brought in Hinduism and became the patrons for Hindu art and architecture. By the eighth century CE temple building started in all parts of the country fashioned in rock, stone, and brick. The construction materials of the Hindus were of simple but effective order. They continued to observe laws of gravity, strength being obtained by the solid resistance of weights acting only vertically, all forces being transmitted directly downwards. In these circumstances mortar was unnecessary because it would have been of no use for distributing the pressure between the courses of the structure, it was therefore rarely applied, with the result that Hindu masonry was described as of the 'dry' order. But this is true mostly for dressed stone masonry which was first seen in the Gupta period[iii].

Large pieces of stone were joined with stone or iron dowels. Local stone continued to be used and till much later one sees the use of sandstone in Orissa and khondalite laterite in Konarak temple in the 13th century. Large stone monolithic stones were used for pillars. By the Gupta period, in the 4th & 5th century AD wall paintings, especially in rock cut caves, reached a zenith and were painted over a plaster made of clay, cow dung, stone powder, rice husk, lime, brick powder and many organic additives. This plaster has been extensively researched and documented by scholars[iv]. Many temples were built in brick with stone cladding or finished with stucco. In around the 6th century AD, the Bodh Gaya temple was built of bricks and clay mortar coated with lime, with granite slabs used as flooring[v].

Summary of the Pre-historic, Buddhist, and Hindu period:

The previous overview indicates that brick and stone remained the major building materials for construction from the pre-historic times to the Hindu period. The archaeological remains of the Indus Valley civilisation show an abundant use of bricks for construction with careful bonding. The Vedic culture, which followed

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i Santosh Saran & Ravindra Singh. History of Science and Technology during the Gupta Period. Prachi Prakasha: New Delhi. 1994.
ii, iii Brown
v Saran

List of mortars & plasters

(Source: Satish Chandra, pages 404-410)

Date	*Source*	*Support*	*Plaster*	*Use*	*Ingredients*
3500 BC-1300BC	Mohenjodaro (Mortar analysis)	Not mentioned	Gypsum Plaster	Site wall	74.12% Gypsum, 20.41% Sand, 2.5% CaCO3, alkaline salts
		Not mentioned	Gypsum Plaster	Site Tank	43.75% Gypsum, 38.04% Sand, 13.78% CaCo3, alkaline salt
		Not mentioned	Lime Plaster	Earthenware Vat	9.58% CaCO3, 21.71% Sand, alkaline salts
		Not mentioned	Lime Plaster (Kankar)	Drain	39.96% CaCO3, 17.43% Clay & Sand, 8.82% MgCO3, traces of Gypsum
	Harappa (Mortar Analysis)	Not mentioned	Lime Plaster (Kankar)	Floor	35.02% CaCO3, 51.39% Clay & Sand, MgCO3, Traces of Gypsum
		Not mentioned	Lime Plaster (Kankar)	Lump of mortar	56.51% CaCO3, 34.35% Clay & Sand, 4.81% MgCO3
		Not mentioned	Gypsum Plaster	Painting	56.6% Gypsum, 42.16 Clay & Sand, 0.94% CaCO3
3rd Century BC	Buddhist Text: Vinay Pitak (1)	Brick	Mud Plaster	Walls & Floor	Clay, Cow dung, ash
3rd Century BC	Buddhist Text: Vinay Pitak (1)	Brick	Mud Plaster	Walls & Floor, grout	Clay, rice husk
3rd Century BC	Buddhist Text: Vinay Pitak (1)	Brick	Mud Plaster	Walls & Floor, grout	Clay, rice husk
4th - 5th Century AD	Text: Vishnu Dharmottar Purana	Stone	Mud Plaster	Walls & grout	Clay, brick powder, cast iron, lime, chalk, organic additives

Bricks from Hindu, Muslim, and Colonial period

Date	*Source*	*Support*	*Plaster*	*Use*	*Ingredients*
2nd Century BC - 6th Century AD	Ajanta Style	Basalt	Mud Plaster	Walls & grout	Mud, cow dung, stone powder, lime, organic additives
Early 7th Century AD	Bagh Style	Stone	Lime plaster	Walls & grout	Lime, red clay, gravel, hemp fibre
10th Century AD	Nagara Text: Samaranga Sutradhara	Stone	Mud Plaster	Walls & grout	Clay, sand, organic additives
11th Century AD	Vastu Shastra text: Apparajita Praccha	Stone	Mud Plaster	Walls & grout	Chalk, red ochre (clay), yellow ochre (clay), organic additives
12th Century AD	Dravida Text: Abhilashitartha Chintamani	Stone	Lime plaster	Walls & grout	Chalk, powder of conch shell, gum, organic additives
16th century AD	Dravida Text: Silparatna	Stone	Lime plaster	Walls & grout	Lime from conch shell, sand, organic additives
16th century AD	Jaipur Style	Stone	Lime plaster	Walls & Floor, grout	Lime, marble chips, marble powder, organic additives
Late 16th Century AD	Chamba Style	Mixed medium (stone, mud, bricks)	Mud Plaster	Walls & grout	Clay, lime, sand, fibres

this period, used natural materials like wood, mud, and straw. They soon became proficient in the use of timber construction. But because of the perishable nature of these materials most of this does not survive but has been carefully documented in the rock cut structures that were built by the the Buddhists at the same time or later who wished to make permanent monuments for their faith. These details were faithfully replicated in these stone monuments. Buddhists also used a lot of bricks for the construction of their stupas and viharas. The later Hindu rulers continued the use of brick, dry ashlar masonry, and stone clad brick construction. A lot of bricks structures were also finished with lime plasters and stucco. The above chart prepared from the research appended conducted by Satish Chandra indicates the use of mud, gypsum, and lime as the basic materials used for mortars and plasters during this period. However, it is important to understand their use during that period and how it is different from our understanding of the same materials in the current times.

Non-standard and large brick sizes: Misra in Ancient Indian Bricks and Brick Remains writes that primitive man found use in soil for construction initially as lumps (Greenhard) and later as 'Packed' earth and then as 'Leather Hard' earth. This led to the use of sun dried bricks and finally as baked bricks by about 3500 BCE. Many texts were written during the Vedic period called the Vedas during 1500-1000 BCE on various subjects including architecture. Consequently many texts were written, the one pertaining to architecture being Mansara, which was written in the 5th century AD during the Gupta period. These texts consider the earth as the first brick and give other elated information. Bricks are then distinguished as male, female, and neuter depending on their size and shapes. Male bricks were used in the construction of temples for male deities and female bricks for female deities. Curved and shaped bricks were considered neuter. Brahmins could use big bricks and smaller ones were for lower castes.

The first point to note is that brick sizes vary from three inches long to about two feet long with varying proportions and thickness. Bricks were, so to speak, made to order; larger bricks were used to cover drains, honeycombed bricks for sockets of doors, L-shaped bricks for corners, and wedged shaped for rounding. They were moulded for decoration and detailing thus

Stonework resembling woodwork, Sarnath

the possibilities of the entire artistic expressions were completely taken up through the medium of bricks where necessary and the stone was not available[i].

Construction of brick and stone walls: The second point to note here is the construction system that was employed to make the brick structures. For the 5th -8th century AD Saran & Singh write, "Brick laying mostly follows running stretchers but sometimes it follows course of alternate header and stretchers. The exterior portion of the building was often decorated by using special types of bricks." They continue to write that the outer walls of the buildings were unusually thick with the Sarnath monastery having

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i T.N. Misra. Ancient Indian Bricks and Brick Remains. New Delhi: Harman Publishing House. 1997.

Brickwork & terracotta in archeological site, Sarnath

Plasterwork over brickwork, Sarnath

5.5 feet thick walls to 7 feet at Bahari. The Dashavatar temple in Deogarh has walls that are 3 feet and 7 inches thick whereas the room size is only 9 feet nine inches thick. One can safely conclude that the construction of the walls was not as we know them today, where bricks are much thinner and have a proper stretcher to header bond. Care was taken to give the exterior facade a neat finish but the inner bulk was filled with brick concrete, with bricks acting as aggregates. Sometime times they were filled with burnt clay nodules or brick bats[i]. One of the 11th century texts, Samaranga Sutradhara, lists twenty features of a 'well laid masonary' which included they being well marked, well jointed, and levelled. A string was used to guide the course and the mortar was not to be in excess[ii].

When comparing this information with the actual archaeological remains, it may be safe to assume that the directions were for the facade blocks and not for the core. Whereas the facade often had a finished look with bonded courses, the core was often brick or stone rubble. The rubble core was given a final layer of lime plaster or stucco, terracotta or decorative bricks, and later clad with stones.

Load bearing spanning systems: The third thing to note is that the roofs were either made of wood, timber, or in the case of temples, corbeled arches. The technique of corbeling requires successive horizontal layers of bricks or stone so laid that each projected slightly beyond the one below, progressively narrowing the space at the top till the opening becomes small enough to be covered by a single slab of stone. This system of construction was replaced by the more effective arcuate system brought to India by the Muslims. If one analyses the construction system, three things can be noted. Firstly, the construction system was primarily load bearing where the bricks walls were wholly in compression. Secondly, the roof structure too, was in compression, barring a very small section which was cantilevered or when spanned with timber beams. And thirdly, the facade of the buildings were treated with care to present a 'neat' look and was sometimes covered with decorative bricks or stones or plaster.

It is important to understand that the main structure was in compression and almost no tensile stress was present in the thick walls. The mortar was used simply to provide enough friction for the units to stay together during construction and also to provide a levelling material to cover the surface undulations and provide full surface contact and uniform load transfer to lower brick. Ashlar masonry was constructed using no mortar and stone blocks were usually tied together with iron dowels. Sometimes thin organic adhesive joints can be found in such construction. This system continued to be used while cladding brick structures with stone.

Mortars and plasters treated differently: Finally, texts like Mayamata, mention five types of 'mortars': Gulmasha, Karala, Mugdi, Kalaka, and Chikana. All are made of sand, lime, gravel, and shells but gradually

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i Jaggi

ii Vibhuti Chakraborty. Indian Architectural Theory. Delhi: Oxford University Press. 1999.

become finer from the first type i.e. Gulmasha, to the last, where Chikana is a homogeneous and viscous liquid[i]. Satish Chandra mentions that Indian mythological books like Shipratna, Mansoullas and Abhilashitarth Chintamani, Vishnudharmottar Puran mention a unique plaster called Vajralep (Stone hard). He continues that the main purpose of these plasters was to join bricks and stones, but they were also used for plastering walls.' There were four types of Vajralep, made by mixing mud, lime, sand, burnt clay, stones, and organic additives, mainly fibres, gum, and fruit pulp[ii]. The list presented earlier, and prepared based on the studies by Satish Chandra, gives an overview of the materials used during this period.

It may be safe to assume that 'mortar' and 'plaster' has been inter-changeably used as a generic term by the translators and scholars. Brick and stones structures built during this period were mostly of dry ashlar and very thick walls that did not require a very strong mortar, so mud or clay, as mentioned in many places would suffice. However, the plasters would have be of much better quality to keep out the damp, give a finished surface for render, or to point the stone joints. It was in these places that lime plasters may have been used. Lime was not readily available everywhere and clay was a common construction material, and thus less expensive than lime, so it makes more sense for the builders to use mud mortars and lime plasters in their buildings. Mortar analysis of buildings from the Indian sub-continent make this theory more and more probable to accept.

Iron dowels used for cladding stone, Vishwanath temple premise, Varanasi

Stone cladding over brick core, Dhamek stupa, 500 CE, Sarnath

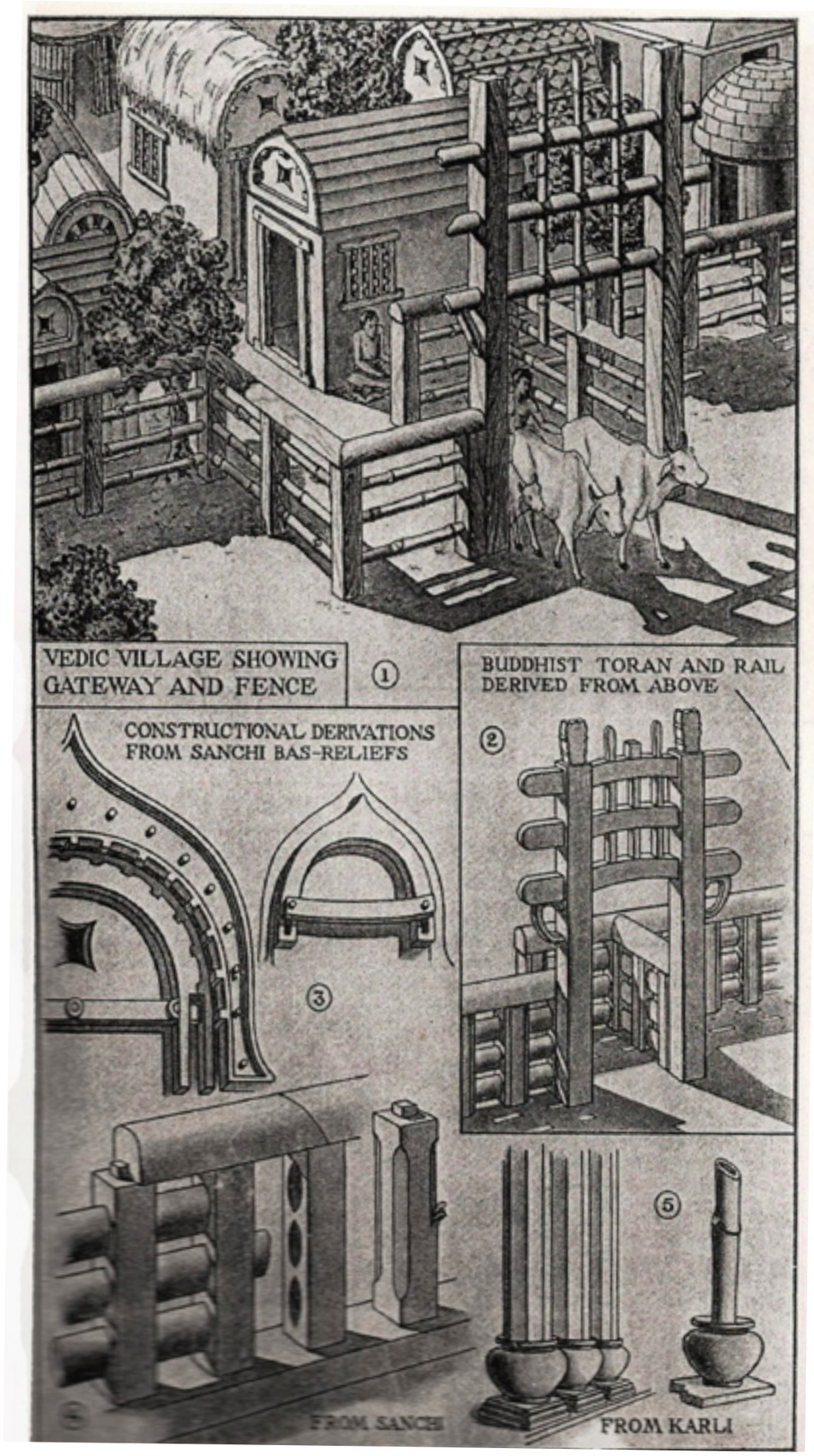

Illustration of wood work during Vedic period, Source: Percy Brown

i Chakraborty

ii Satish Chandra (page 408–410)

Building Construction during Mughal Period, Source; Qaisar Jan

Chapter 3:

Advent of the Muslims (11th century to 18th century AD)

Ceiling of Kuwwat ul Islam Mosque built from architectural fragments of earlier structures, Delhi

Overview:

Architecture, according to Ibn Khaldan, writes Ahsan Jan Qaisar, is one of the necessary crafts. Apart from natural shelters like caves and caverns the history of artificial shelter progressed from house made of reeds, clay, and timber, to those of brick and stone. In structural terms the basic dimensions are walls, columns, beams, and arches. The way each of them differed from each other was the manner in which these dimensions combined and their materials for construction used. From this point of view, Muslims in India used arches, domes, minarets, mihrabs, geometrical and floral patterns, and calligraphy on stone, all of which was quite different from the pre-Muslim India[i].

The displacement of the beam with the arch was one of the major shifts from Hindu to Islamic architecture. But this was made possible by shifting to a new construction system that used mortar and concrete. The simple method of placing stones or bricks one on top the other by the Hindus, a system acting in compression with vertically downward forces, was now replaced by a more sophisticated system having additional diagonal forces to span spaces where larger spans could be covered, the structure also being stronger and more economical, and provided larger and more open floor spaces. However, the traditional knowledge of stone masonry, stone carving, brick and terracotta construction of the Indian craftsmen was also slowly integrated with the foreign influences brought in by the new Muslim armies who invaded India after the 11th century and became rulers after the 13th century.

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i Qaisar, Ahsan Jan. Building Construction in Mughal India. The Evidence from Painting. Oxford University Press. 1988. (Centre of Advanced Study in History). (page 1-5)

Rubble work in Jahanpanah, Delhi

Thin lakhori brick arches, Lucknow

The Islamic architecture in India has been studied under three phases: The first phase from the 11th to the 13th century saw the destruction of Buddhist and Hindu structures and the use of the plinths, carved pillars, and other dismantled architectural fragments for the construction of new mosques and tombs. The second phase, called the Delhi Sultanate, which lasted from the 13th century to the 16th century CE, saw successive import and development in the design, construction, and articulation of religious buildings, forts, and palaces. The third, and the last phase, also considered as the culmination of the Islamic period was brought in by the Persian invaders or the Mughals. They infused new designs and sophistication to the Islamic architecture by including gardens, water elements, and aesthetic details to their buildings.

Whereas the first phase continued to use the traditional materials and systems of the Hindus, the second phase extensively used rubble masonry finished with plaster. Since the masonry was coarse, a very thick plaster had to be used to get a finished surface. Use of stone masonry, monolithic and carved stone pillars, bricks and terracotta tiles continued, but were now used to develop true arches, vaults, squinches, and domes. By the time the Mughals came into power, the Indian craftsmen had perfected the art of making arcuate structures, planning of tombs and mosques was now generally uniform, and the construction system consisted of walls and roofs, both quite thick, which had a brick or rubble stone core clad with dressed stone, especially marble. Foundations, plinths, and floors, were also arcuate, were made with the same system. Stucco or external lime plaster was used to imitate stone, if marble was not readily available.

For the purpose of our study of mortars for restoration, what was happening in and around Delhi is very important, but of far greater importance is what was happening in buildings generally called Provincial architecture, that is, buildings constructed during this period, but in other parts of the country. India is a big country with varied geographical and geological features. This offers great variety in the building materials that are used for construction. In the Himalayan region, where timber is freely available, most structures were built of wood. Laterite is commonly used in the Deccan plateau, and bricks have been employed throughout the northern Gangetic plains which has good quality soil.

It may be noted here that the bricks used during the Islamic period were quite small, smaller and thiner than contemporary bricks, but strong and well baked. They were also used as an aggregate for the concrete that formed the core of most buildings. These thin bricks were also used effectively for floral and arabesque designs for surface articulation and finally finished with stucco. The brick surface formed a stable base for the decorative stucco. A literature study of several books written about the Islamic period bring to light the use of many types of mortars and plasters but the same study could not be made for the earlier periods since many structures were demolished and re-built by the new rulers.

Literature review:

Satish Chandra confirms the constructional principle applied in India before the Turkish conquest was 'trabeate', in which all openings were spanned by means of beams laid horizontally[i]. Through this technique, the resultant structures would be flat roofed and low. No tall buildings or open walled structure could be constructed and had to be supported by innumerable pillars. Built of heavy building materials, generally stone, they also did not need mortar or any cementing material, gravity holding them together. Iron clamps were sometimes used for joining. With the weight of the roof, built with staggered or corbeled members, resting directly on the walls, the structures were not very durable. This traditional system built only for compression was challenged after the 10th century AD by the new rulers.

New types of building materials and concepts of planning and construction were introduced by the Muslim rulers. Stone was gradually replaced with bricks and brick tiles, lime mortar and gypsum was used for binding. The use of gypsum and lime along with surkhi (powdered brick) appears to have become common after this period. Lime plasters or stucco, was used for decorative surfaces, even finishing of drains and floors. The author points out that lime, gypsum, and powdered bricks which were used in the Indus cities of the third millennium BC and were discontinued, again saw a revival during the Muslim period which were influenced by the Byzantine and Sassanid Iran rulers.

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i Chandra, Satish. History of Architecture and Ancient Building Material in India, Part 1&2, New Delhi, Text Books International, 2003

Marble cladding, Taj Mahal, Agra

The Delhi Sultanate:

These new materials, i.e. brick and mortar made of lime, surkhi, and gypsum, led to cheaper costs of construction and thus more number of permanent structures could be made. Earlier, only public structures and places of worship were constructed of permanent materials, but now in addition many more secular buildings like palaces, serais, and bazaars could be made. These new materials also aided the newly introduced arcuate technique of construction. The use of smaller building blocks, bricks and rough dressed small stones in this case, joint together by mortar and in compression, could span much larger spaces without the use of flat lintels and pillars, giving a larger un-obstructed space. This construction system needed a good binding material which the lime-surkhi plaster provided. By the 14th century AD, the Tuglaq rulers used stone rubble for construction in abundance which was bonded with and covered by a thick layer of lime plaster or faced with stone. [i]Use of carved stone, brickwork finished with coloured and decorated stucco, decorative bricks, and brick tiles, became quite popular during this period which ended in the 15th century AD.

Muntakhab-ut-Tawarikh gives the following details of building a fort in Gujarat in the sixteenth century; "The architects (AD 1572) skilled in geometry and expert in subtleties carried the foundation of the fort down to the water, and also dug a moat of the same depth, and on the two sides of the fort which adjoined the land, they built a wall of stone, adamant (stone which is hard as diamond) and burnt brick. The length of the wall was 35 yards and their height as well as depth of the moat was 20 yards. The centres of each two stones was joined with iron clamps, and the interstices and joints were made firm with molten lead.[ii]" This indicates that the traditional systems of dry construction continued along with the new construction systems.

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i S. Ali Nadeem Rezavi. Medieval Indian Architecture. Indian History Congress. 73rd Session. Mumbai. 2012.

ii O.P. Jaggi, Science and technology in Medieval India. New Delhi, Chandigarh, Jaipur, Lucknow: Atma Ram & Sons. 1977.

Overview of Materials by S. Ali Nadeem Rezavi, Medieval Indian Architecture (2012):

Ruler	*Date*	*Place*	*Construction*	*Materials*	*Remarks*
Muhammad bin Qasim	8th century	Deybul & Mansura, Sindh	Stone was replaced by square sized burnt bricks	Brick, brick tiles, white lime mortar for basement, gypsum with lime mortar on upper levels	Residential & Palatial buildings
Ghaznavide	10th century	Giri, near Taxila	Use of gypsum and lime with surkhi becomes common	Built in brick and brick tiles set in lime mortar & plastered with lime surkhi plaster	Fort
Delhi Sultanante	13th century	Lal Kot, Delhi	Beginning of arcuate construction in brick	Rooms covered with lime plaster, drains finished with fine lime plaster, fresh lime floors, and lime plastered alcoves	All buildings
Tughlaqs	14th century		Stone rubble sloping walls instead of ashlar	Needed heavy use of lime mortar and thick lime plaster and/or faced with dressed granite stone	All buildings
Lodis	15th century	Tomb of Sikander Lodi	Arcuate and trabeated mixed	Stone with lime mortar	Tomb

The Mughal Period:

Qaisar has used literary sources, Mughal paintings, and extant traditional building crafts to compile information about the Islamic period. She writes that clay, bricks, stone, and wood were the basic building materials of this period. The stone used was of various kinds; red, yellow, black, and white. Stone was also used for making doors. Red sandstone and white marble was most commonly used especially in buildings when quarries were located near by. When stone was not readily available, baked bricks, half baked bricks, and unbaked bricks were used. The extensive use of bricks in India after the arrival of the Muslims might have been the result from the need to make true arches and domes due to it's easy availability and handy size. Brick was also a boon to the urban middle class who could now afford to make permanent houses as it was more economical than stone. Burnt terracotta tiles were used for roofing and water sprouts[i].

The basic ingredients for preparing mortar, plaster, and whitewashing was the same although special materials were added as per requirement. The simplest, and oldest, cementing material was plain fine earth or clay mixed with water. Straw was mixed to improve its quality. This was also used as plaster and known as 'gara' in north India. Lime mortar is supposed to have been introduced in India by the Muslims. Qaisar writes that George Watt observes that the stone buildings in south India have 'stone so fitted into each other.… that they have remained in position for centuries without a cement'. J.D. Beggar, who surveyed the monuments around 1871-2 in and around Delhi, also mentions that in north India 'Hindu architecture of the pre-Muhammadan period appears to have used mortar as little as possible, except on roof, to keep out water effectually, and in the floor as a substratum…in the walls of the fort the core is built of rubble set in mud or reddish earth..In temples, the same, when the walls were thick enough…the external faces of their walls (except the walls of the fort) were of carefully dressed stones, laid without any cementing materials, and secured to each other by iron clamps. It would seem that the earliest examples of lime mortar and

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i Qaisar (page 16-17)

plaster in masonary were used by Sultan Iltutmish[i].'

Qaisar continues that they used three types of building limes; those extracted after burning limestone, kankar (pebbles rich in lime), and from fresh water or marine shells. Limestone came from Gujarat and 'all the waggons which come to Surat from Agra or any other place….(are) were compelled to carry lime, which comes from Broach,' mentions Tavernier. He adds that, as soon as it is used, it becomes as hard as marble. Abul Fazl mentions that it was 'white and soft'. But 'Lahori' asserts that the best lime was from Patiali which was more superior than the one obtained from 'sang marmar'. Kankar lime was the most commonly used lime in India and was available in abundance in the plains of north India. Shell lime was prepared in Bengal till the nineteenth century. After burning and slaking lime, additives such as hemp, gum, glue, jaggery, and pulverised brick were added. But kankar lime and brick powder (surkhi) were the basic ingredients for making mortar. The first mention of surkhi can be traced back to the fourteenth century. Watt observes that it appears that surkhi generally took the place of sand in India. However, sand was used on special occasions. One source mentions that the outer walls of Shahjahanabad were made of stone and mud, but they soon developed cracks due to heavy rains and had to be re-built with stone and 'saruj' which is lime, sand, and wood ash[ii].

Coming to plasters, Abul Fazl describes two types of plastering techniques, one of which seems to be a plaster (astarkari) and the other a finishing coat (sandalkari). Qaisar continues, that before plastering, walls and ceiling were given a thick coating of 'kah gil', a mixture of straw, earth, and water. A lime surkhi plaster was applied on it and finished with a coat of 'lime, milk, gum, and sugar.' She quotes Pelsaert, 'when the walls have been plastered with lime, they apply this paste, rubbing it with well-designed trowels until it is smooth; then they polish it steadily with agates, perhaps for a whole day, until it is dry and hard, and shines like alabaster, or can even be used as a looking glass.' For simple white washing, lime and water was used.

Sometimes a white and greasy clay or ochre colour earth (geru), which came from Gwalior, was also used. Visitors to Mughal buildings have remarked that 'the stones of these buildings are so cunningly fitted that the joints are scarcely visible' and 'the end of a hair could not find a place between them.' But all stone work during this period was done with lime mortar. 'Afif', in the book mentions two terms, 'rekhta' that is used for mortar and plaster, and stone and mortar or 'sang o gach'. It may be interpreted that 'gach' is mortar and 'rekhta' is common plaster and 'astarkari' mentioned earlier may be a render[iii].

Qaisar notes that A.C.L. Carlleyle reported in 1871-72 that the exterior of the Moti Masjid in Agra was faced with slabs of red sandstone and according to the Indo-Muhammadan architecture, the core of the walls are filled with rubble brick bats. A similar observation was made by Cunningham about the outer walls of the Agra Fort built by Akbar where 'rubble wall faced with red sandstone slabs bound together with bad powdery mortar'. The inner walls were 'a compact mass of well built walls of rough stones and hard tenacious mortar.' Qaisar adds that the paintings do not indicate this system for brick walls. Thevenot has mentioned for 'Houses of Surat' that the buildings were well built in brick and lime because there 'is no Stone in the Country'. But he adds that 'brick and lime are very dear' and they have tiled roofs on timber and only the rich can afford to make such houses. 'The meaner sort of people' he adds, live in houses made of 'Canes, and covered with the branches of Palm tree'. Could he be mentioning 'kutcha' houses in cheaper materials, even mud and unbaked bricks[iv]?

O. P. Jaggi, in his book Science and Technology in Medieval India, quotes Sir Isaac Pyke, Governor of St. Helena (in a letter to Edmund Halley) as "Method of Making the Best Mortar of Madras in East India." This was reported in an article that appeared in a publication of the Royal Society, London, in 1731-32. This has been widely published in several other books and magazines and gives an idea of the mortar and plaster used by the end of the 18th century and is worth quoting as it gives important insights into the pre-modern construction industry.

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i Qaisar (Pages 18-19)
ii Qaisar (Pages 19-20)
iii Qaiser (Pages 20-23)
iv Qaiser (Pages 29, 44)

Take fifteen bushels of fresh-pit sand well sifted; add thereto fifteen bushels of stone lime. Let it be moistened or slacked with water in the common manner and so laid two or three days together. Then dissolve 20 lbs of jaggery which is coarse sugar (or thick molasses) in water, and sprinkling this liquor over the mortar, beat it up together till all be well-mixed and incorporated, and then let it lie by in a heap.

Then boil a peck of gram (which is a sort of gram like a tare or between that and a pea) to a jelly,and strain it off through a coarse canvas and preserve the liquor that comes from it.

Take also a peck of myrobalans and boil them likewise to a jelly, preserving that water also as the other and if you have a vessel large enough, you may put these three waters together, that is the jaggery-water, the gram-water, and the myrobalans. The Indians usually put a small quantity of fine lime therein, to keep their labourers from drinking it. The mortar beat up and when too dry,sprinkled with this liquor, proves extraordinary good for laying bricks or stone therein, keeping some of the liquor always at hand for the workmen to wet his bricks therewith, and if this liquor prove too thick, dilute it with fresh water.

Observe also, that the mortar here is not only to be well beaten and mixed together, but also laid very well, and every brick or piece of brick slushed in with the mortar and every cranny filled up, yet not in thick joints, like the common English mortar, and also over every course of bricks, some to be thrower on very thin: and where the work had stood, though not for a breakfast or a dining time, (previous days work) before you begin again wet it well with this liquor with a ladle, and then lay your fresh mortar; for this mortar, notwithstanding its being thus wetted, dries much sooner than one used to it would conceive, but especially in this weather (warmer than England).

For some very strong work the same mortar above is improved as follows: Take coarse tow and twist is loosely into bands as thick as a man's finger (in England ox-hair is used instead of this tow), then cut it into pieces of about an inch long and untwist it so as to lie loose, then strew it lightly over the other mortar which is at same time to be kept turning over so this stuff to be beat into it, keeping labourers continually beating in a trough, and mixing it till it be well incorporated with all the parts of the mortar. And whereas it will be subject to dry very fast, it must be frequently softened with some of the aforesaid liquor of jaggery, gram, and myrobalans, and some fresh water, and when it is so moistened, and beat, it will mix well, and with this they build (thoughit is not usual to build common house walls thus) when the work is intended to be very strong, as for example Madras Church Steeple, that was building when I was last there, and also for some ornaments as columns, good arched work, or imagery set up in gardens it is thus made.

Though for common buildings about Madras, where the rainy season holds not above three months in the year, and sometimes less, they usually lay all the common brick-work in a loomy clay, and plaster it over on both sides with this mortar, which is yet farther to be improved. Thus far for building mortar.

Having your mortar thus prepared, as is before described, you must separate some of it and to every half bushel, you are to take the the white of five or six eggs, and four ounces of ghee (or ordinary unsalted butter) and a pint of butter-milk beaten all well together. Mix a little of your mortar with this, until all your ghee, whites of eggs, and butter-milk be soaked up; then soften the rest well with plain fresh water, and so mix all together, and let it be ground, a trowel full at a time, on a stone with a stone -roller, in the same manner that chocolate is usually made or ground in England; and let it stand by in a trough for use. And when you use it, in case it be too dry, moisten it with some water,of the before-mentioned liquor. This is the second coat of plastering.

When your first coat of plastering is laid on, let it be well rubbed on with a hardening trowel, or with a smooth brick, and strewed with a gritty sand, moistened as occasion requires, with water, or the before-mentioned liquor and then well hardened on again; when half dry, take the last-mentioned composition for your fine plastering and when it is almost dry, lay on your whitening varnish; but if your work should be quite dry, then your chunam liquor must be washed over the work with a brush.

The best sort of whitening varnish is thus made. Take one gallon of toddy, a pint of butter milk, and so much fine chunam or lime as shall be proper to colour it; add thereunto some of the chunam liquor before mentioned, wash it gently over there-with, and when it is quite dried in, do the same again. And a plaster thus made is more durable than some soft stone and holds the

weather better in India, than any of the bricks they make here.

In some of the fine chunam that is to endure the weather, and where it is likely to be subject to much rain, they put gingerly oil (Oleum sesami) instead of ghee, and also in some they boil the bark of the mango tree, and other barks of astringent natures, and aloes which grow here in great plenty by the sea-shore, but to all the fine chunam, that is for outside plastering, they put butter-milk which here called toyre. And for inside work they use glue made very thin and weak, instead of size, for whitewashing; and sometimes they add a little gum to it.

The plastering above-described, is thought in India vastly to exceed any sort of stucco-work or Plaster of Paris, and I have seen a room done with this sort of terrass-mortar that has fully come up to the best sort of wainscot-work, in smoothness and in beauty. Thus we see how indigenously fabricated products brought very good results[i].

In the same book, the author continues to add: *In a letter to Sir Joseph Banks, President of the Total Society, Dr. Helenus Scott, in 1790, mentions about a similar mortar which he states is used for under water works. He states: "For works below the surface of water, I think the Indians have an excellent method of preparing their chunam. In a few hours it acquires great solidity and especially the part of it that binds together the large stones which face the walls; for most trouble is taken with the chunam for that purpose. One of the chief ingredients is a kind of unrefined sugar which appears by Mr. Bergman's experiments to contain more of the disengaged saccharine acid that refined. With this and some other substances, the chunam is carefully mixed for a length of time and is occasionally wetted with a solution of the sugar in water*[ii]."

Observation and Interpretations

The new Muslim rulers, after the initial phase of destruction and re-assembling of old building parts and traditional craftsmanship, brought with them new designs and construction systems which could not be built in the old and traditional systems of the Hindus. For their arched and domed tombs, and large prayer halls in mosques, they needed smaller units like bricks and a strong mortar that could take care of the tensile stresses. The clay mortars, dry ashlar masonry, or organic adhesives used by the earlier builders had to be replaced by lime, surkhi, and gypsum mortars. Building limes and surkhi were used at a large scale after the 15th century. Building limes varied from region to region. The old alluvial soils of the Gangetic plains produced a lot of kankar lime, the western regions of Gujarat had limestone reserves, whereas shell lime was procured from the Eastern parts of India. But it was common to use locally available materials, including stones.

Whereas openings, plinths, and foundations of buildings built during this period were also arcuate, the walls continued to be load bearing and were quite thick, and made from rubble stone masonry, and later of brick concrete, where the bricks were quite small thin and small, and mortars rough and in abundance. This became the common method for making walls for up to the 18th century, which were covered with a thick coat of lime plaster, laid in one or more layers, and finished with stucco, white wash, or clad with stone. Lime and surkhi continued to be the main materials for mortars and plasters but use of mud and clay in mortars continued, as did the use of dry ashlar masonry.

More variations in materials and construction systems can be seen in the buildings built during this period in the various provinces which were usually dependent on local climatic and geological conditions and availability of materials and craftsmen for example areas along the Gangetic plains continued to use a lot of clay, whereas the Deccan regions used laterite. Timber and stone continues to be used in the hilly regions in the north. The variations and decisions of use of materials was based on the building type, importance of the structure, and the financial condition and status of the patron.

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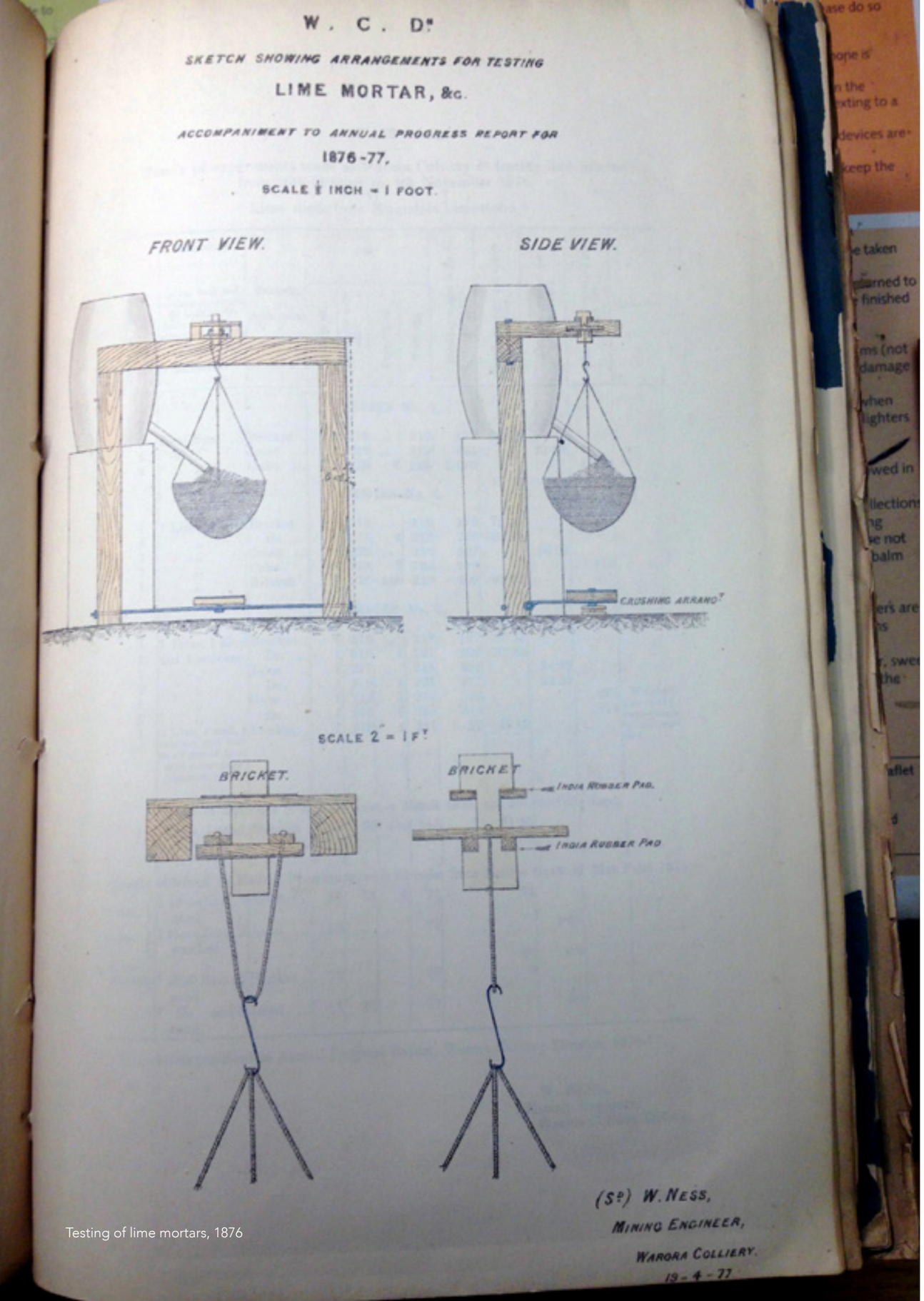
i, ii Jaggi

Female sieving lime, Source: Qaisar Jan

Men making lime mortar, Source: Qaisar Jan



Testing of lime mortars, 1876

Chapter 4:

East India Company, the Colonial Architecture, up to Independence

Background

Europeans started visiting India from the 16th century onwards, with the Dutch East India Company, French East India Company, and by 1600 with the East India Company, all formed to trade with India. But no major major changes in the field of architecture and construction happened till much later in the 19th century. Europeans, who came as traders, mostly used local materials and local technology for the construction of their factories, warehouses, and other buildings. The earliest important structures made by the British in India were the Fort St. George and factory at Madras, built in 1600 CE; Mint and Printing Press in Bombay, built in 1669 CE; the Mazgaon Fort in Bombay was constructed in1690; the city of Calcutta was founded in 1700 CE and the Fort William constructed soon after in 1702 CE. After the forts, churches were the first religious structures to be built in these cities. St. Mary's in Madras (1700); the Armenian Church also in Madras (1712); the St. Thomas Cathedral in Bombay (1715); another Armenian Church in Murshidabad (1757), the old capital of Bengal; and the St. John's Church in Calcutta (1780) were built. Other buildings of note in the 18th century were in Lucknow which included the Residency (1780), which was the residential quarters of the Resident and other Europeans, Constantia (1800), a private house of a French trader, and the Iron Bridge (1781).

Sten Nilsson, in his book European Architecture in India (1750-1850), writes in some detail about the construction technique of this period. Nilsson mentions that many travellers who came to India were interested in architecture and construction and wrote about it in their memoirs. Nilsson has made a survey of the 18th century based on such accounts although most of his information is from one such book written by Thomas Williamson, East India Vade-Mecum (1810), and writes that the greater part of European architecture in India was erected in brick, mortar, and plaster as stone was not easily available. The Indian workers built for Europeans in the same manner as they had built for the Mughal princes. A characteristic feature of their work was the bricklaying technique which was carried out with great care with relatively small, thin and almost square bricks, called lakhori. The first Fort William in Calcutta was constructed of such diminutive elements, as were many structures in Lucknow. However, the conditions in Lucknow was special, as the town was for a long time under Indian rulers whereas English bricklayers were recruited at an early stage to a European centre like Calcutta. They were to serve as instructors and were also instrumental in making certain changes like altering the dimension of the structural elements. As early as in 1754, Colonel Scott advertised for bricks measuring 11 X 5.5 X 2.5 inches when burnt, which were much bigger than the prevalent lakhori bricks and closer to the ones in use in the present day. In 1790, one can read a notice in the Calcutta Gazette about 11 inch bricks. It appears that the strength of the bricks were also experimented with and longer burning was demanded than the Indian usually permitted. From the turn of the century (1800) European engineers applied these learnings (earlier made for public works) for simpler buildings such as bungalows, where previously sun dried bricks, so called cutcha, had been regarded as satisfactory. Baked bricks of a bigger size were now commonly used.

Nilsson continues that the greater part of the building lime used for construction in Calcutta area was brought from the Moorungs area (present Nagaland) and transported downstream in big boats. It was slaked before it came on board the boats, otherwise the rain would have achieved the same result, as the voyage sometimes took up to one month. It was felt that the building lime from the Moorungs was inferior to that which was produced on the Coromandel Coast and the Malabar Coast. The lime brought from the Moorungs was produced by burning shells. It was used both for preparing mortar and in the white plaster,

19th century stucco work, Murshidabad

chunam. When transported to Bengal, this lime was rather sensitive to the salt petre content in the air. The sand for the mix was taken from beaches and river banks which was washed and purified. The mortar which jointed the bricks into walls and colonnades was mixed of brick dust, water, coarse sand, and cut hemp and covered with a homogeneous layer of lime plaster, and (sometimes finished with) white facade plaster mixed with lime of burnt shells, the white of eggs, milk and other ingredients[i].

In the 19th century other than brick, stone was also sometimes used. St. John's Church, Kolkata, built in the 1780's has a spire erected in pink ashlar from Chunar. Steps in the Residency in Hyderabad were constructed of light green granite in 1803. Black granite gneiss Tuscan columns were erected in the Fort St. George, in Madras. Marble was shipped in from Italy and England as ballast, and was used for flooring in the St. Andrew's Church, Madras. Wellesley's Government House flooring came from China. Roof tiles and balustrades were often made from terracotta. Wood like mahogany, and teak was often imported as large beams, spars, and planks of all sizes, from Baltic countries, West Indies, Ceylon, and Peru. Indian wood like mahogany, palm, mango, and saul was also used. Bamboo was used for scaffolding and for sun screens. Initially iron was scarce, and bar iron and cast iron was imported but by the middle of the 19th century, iron and iron products were imported from Europe. Glass was rarely used and had to be imported.

After discussing the materials, Nilsson describes the methods of building construction. Mortar for joining bricks into walls and colonnades was mixture of brick dust, water, coarse sand, and hemp. This type of construction was called pucka as opposed to cutcha, which used sun-dried bricks. Door, windows, architraves of columns, and roof girders were made of wood. The whole structure was then covered with a layer of lime plaster. Many of the buildings were

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i Europe in India (1750–1850). Sten Nilsson. Faber and Faber. London.

All Souls Cathedral (1875), Kanpur

finished to resemble European stone structures. Colour played an important factor in this as buildings changed from bright colours in the Baroque treatment by the French, Portuguese, and Danes, to sombre white of Neo-Classical British buildings, to delicate colour effects of the Adam school, and finally to contrasting colours of the Greek Revival. The white was achieved by shell lime whereas the other colours were prepared from imported powder such as white chalk, smoke black, yellow ochre, and Spanish green etc[i].

Industrial Revolution and its impact on the 19th Century:

By the 19th century the East India Company had expanded its trade operations and had started forming residential colonies. Taking advantage of the infighting and unstable political condition of India resulting from a weakening Mughal empire the British, offering protection to one of the warring parties, also gained in political power. In 1751 Madras came under their protection. Winning the Battle of Plassey in 1757 they became masters of Bengal. Mughals and Awadh rulers ceded after the Battle of Buxar in 1764. In 1799 Mysore was conquered and by 1818, with the subjugation of the Marathas, the British controlled most of India.

Along with the rising political power of the East India Company, the effects of the Industrial Revolution in Britain trickled in and could be felt in India. The development of the furnace by Abraham Darby in 1709 that could produce pig iron from coke, resulted in the invention of the steam engine in 1712 by Thomas Newcomers, and the weaving machine by John Kay in 1733 brought in the Industrial Revolution. The power looms could now spin larger quantities of cotton, cloth and steam powered locomotives, railways, and ships that could transport the finished and raw products from one place to another. India now under the British, became a major supplier of raw materials

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i Nilsson

like coal, iron, and cotton for their increasing demand in Britain.

With increasing political and trade activities the British soon became engaged in administration and planning to smoothly run these operations and thereby needed new buildings to run them from. Military engineers accompanied the East India Company companies from as early as 1748 and by 1816 there were military engineering services in six companies. In the 18th century, most building activities by the British was done by these military engineers. But with the growing need of buildings a separate Public Works Department was set up in 1848. Another department of engineering was set up for the railways in 1849. Both these departments were responsible for the construction of railway lines, stations, bridges, culverts and administrative and other public buildings.

To feed this growing demand of engineers the Rookie College of Engineering was founded in 1845. By 1850, three more engineering colleges were opened in Calcutta, Madras, and Poona[i]. The Survey of India, set up in 1767, continued to survey the growing EIC territory in India. The Geological Survey of India set up in 1851 explored the possibilities of sourcing the important raw materials like coal, iron, and cotton. The laying out of the railways in India after 1844 and its formal acquisition by the Great Indian Peninsula of UK in 1849, further enhanced the need for raw materials, buildings, and thus a faster, better, and more economical system of construction than the existing one was developed. The reports from the 19th century by the various agencies like the G.S.I., P.W.D., etc give details of such activities. Many reports about 'poor quality' and 'bad construction' by local agencies is also noted. Thus, much of the first half of the 19th century saw the experimentation and development in the field of construction by the British engineers.

As mentioned earlier the buildings used by the British were constructed with local materials and by local masons. Buildings were sometimes also rented, and were both kutcha (made of un-baked bricks) or pucka (made of burnt bricks). The bills from one of the 18th century settlements in India was the Residency in Lucknow, set up in 1775 to house the British Resident. The bills presented to the East India Company in 1777 for the 'Expense of erecting' and repairing several bungalows for offices and residences indicates that old buildings were being used even as new ones were being constructed. In 1778 a report to the Governor General indicated that a fire in the Residency Treasury 'destroyed entirely the Straw Buildings where the Treasure had always been kept' and that a strong 'Brick Building' be made. The roofs of buildings during the 18th century were mostly out of inflammable materials like straw and timber.

The construction of buildings during this time was in the hands of local masons, British military engineers, and European amateur architects. They all used pattern and architectural books to create European buildings in India. It is important to note that even the engineers of the military services had a very rudimentary training for construction of fortifications not houses. For construction details the architects and engineers relied on local masons or on books like The Builder's Magazine: "Monthly Companion for Carpenters, Masons, Bricklayers, as well as every Gentleman." Along with plans and sections of designs, the book also gave detailed notes about various types of bricks which are most suitable for different types of buildings. It was not until 1812 that the Institution for Royal Engineers was founded at Chatham and in 1826 C.W. Pasley, principal of the institution published his handbook Outline of a Course of Practical Architecture, compiled for the use of junior Officers of Royal Engineers, who were sent to the British colonies[ii]. Slowly in the 19th century the complaints of the engineers and builders regarding the 'poor quality' of construction, hazards of fire with the straw and timber roofs decreased, and construction systems acceptable by 'British' standards were developed.

The beginning of the 19th century thus, saw great experimentation in both design, and construction of buildings, built by the British. There is evidence of large, almost stone sized bricks used for construction of barracks and other buildings of the East India

i Anthony Farrington (ed). The Records of the East India College. H.M.S.O. London. 1976.

ii Rosie Llewellyn-Jone. The Fatal Friendship. Delhi: Oxford University Press. 1985.

Brickwork and pointing details, All Souls Cathedral, Kanpur

Company as it was faster to construct than when using small palm sized lakhori bricks. Constantia, completed in 1800, was built by bricks much like the modern day bricks. In addition, circular and other shaped bricks were also used in Constantia and in other buildings of the same period. However, it was only with the coming of the Railways in 1844, that the construction system was standardised by the British. The construction of a railway line involved the formation of the line, ballasting and laying of the permanent way, and the building of stations, workshops, towers, bridges, and culverts. All this needed good quality materials and supplies in large quantities, especially stone for ballast, iron & steel, bricks and mortar.

The heavy demand for good bricks stimulated and rationalised brick making in India. Traditional Indian processes turned out bricks that were irregular, and fired unevenly. This forced the Railway engineers to ensure that not only a large number of bricks were available but they were also of good quality, since where stone was not available, bricks were used to make ballast. Detailed instructions for brick and mortar making were provided to the overseers of the BB & CIR (Bombay, Baroda & Central India Railway, incorporated in 1855) in 1858. The report mentions that 'two acres of land had to first be acquired nearby to develop a brickyard which had appropriate deposits of clay and water. Clay was mixed with pug mills driven by bullocks. Sheds for drying and kilns for firing were set up for a capacity of 100,000 bricks'. The traditional wooden moulds were replaced by brass moulds, which once mastered, enabled the moulder to turn out more bricks per day. The effort to make good bricks was continuous as different local conditions across the length and breadth of India demanded different approaches and local 'habits and methods' of labour had to be broken to achieve the desired results[i].

The end of the 19th century thus saw great changes in the field of construction and technology in India. Whereas bricks had being used in India for several centuries, and were the basic building blocks, they metamorphosed from the large ornamental ancient bricks and small palm sized lakhori medieval bricks to a size in between, much like our present day bricks. Unlike the earlier 'brick concrete', bonded brick work was now used to construct walls, which as a result became much thinner. The brick kilns, brick moulds, and other systems of producing bricks were modified and standardised. But the major changes came in the preparation and use of mortar.

Firstly, the local Indian mortars had great variations, were considered non-scientific, and were different from British systems, and thus difficult for the British builders to understand. Secondly, since the British engineers were working across India, especially while laying out the Railways, they needed systems that could be carried out uniformly in all divisions and units. With the efforts by the Railway engineers, brick making could finally be standardised and was found satisfactory as per 'British' standards. They continued their experiments and efforts at documenting and recording the local systems and trying to arrive as some standards. Thirdly, the findings of the surveys and operations of agencies such as the Geological Survey of India, brought to light the availability of

i Ian J. Kerr. Building the Railways of the Raj 1850-1900. Delhi: Oxford University Press. 1995.

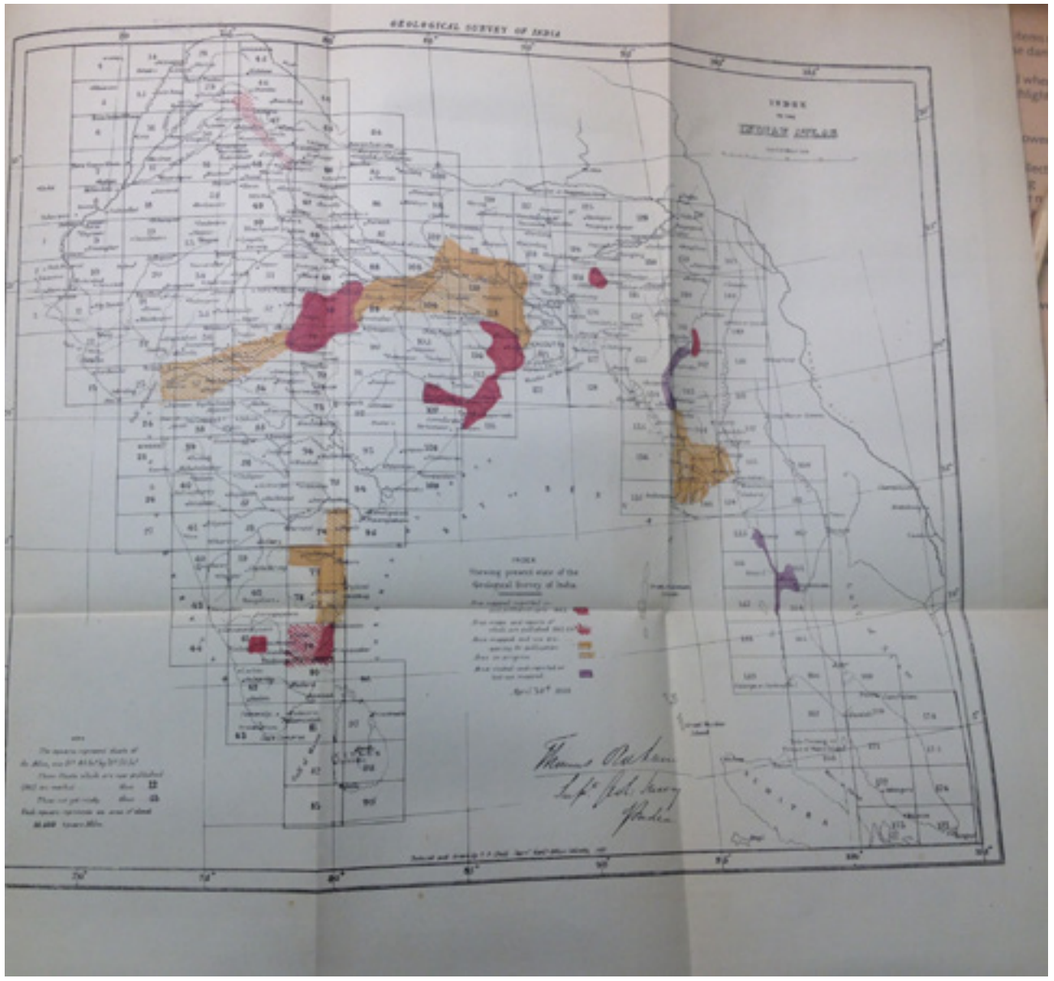
new materials the main being coal, stone lime, and iron which could be used to develop new age or standardised building materials.

The notes made by the engineers in their annual reports, now in the archives of the India Office Library in London tell the whole story of the 19th century standardisation of mortar and the development of cement. In 1806, Bengal Military Consultations (18-25 September 1806) "Expenses mentioned therein for … finest possible masonry laid in mortar made of Black Soorkey".

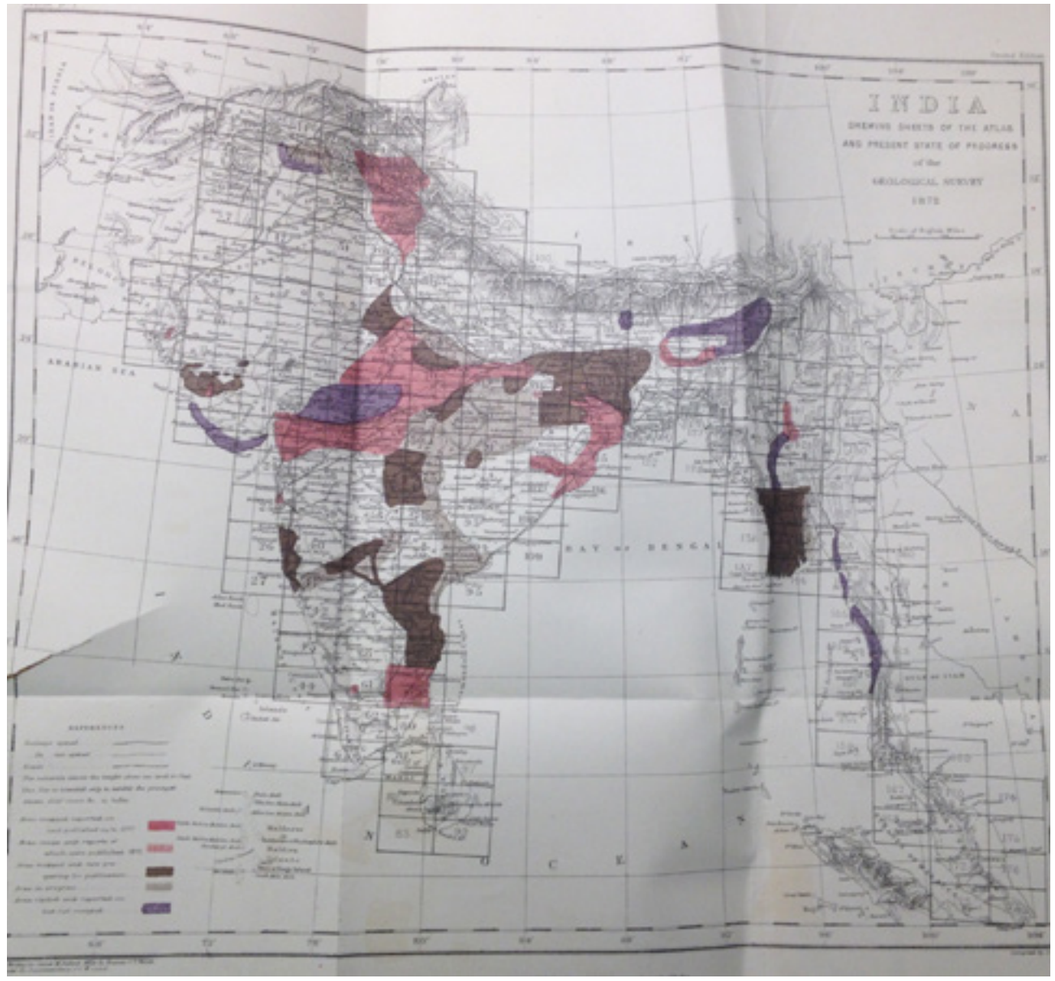
By 1855, Bengal Public Works Consultation Indices (1855 Z/P/628. Fort William August 1855 Circular No 59), states in "MANUAL 'para 6, 88, 89 for the proportion of sand or brick dust to be mixed with lime with a note worth mentioning, "always depend on nature and quality of lime and should be a result of careful experiment. The mortar in Bengal should invariably be hydraulic, either naturally or artificially vide para 72 regarding quality of brick dust and 75 for sand." Details of proportions of mortar are given for foundations, brickwork, pointing, plaster, white wash, brick flooring, and stone flooring. It is interesting to note that for foundations, pointing, and stone flooring, stone lime is used. Kunkar lime has been specified for brickwork, and hydraulic lime for plaster. Brick dust or Surkhi was used more commonly than sand as aggregate. (See table attached for details).

The engineers experimented with both kunkar lime found locally and later with stone lime which they found in abundance during their surveys in the production of iron. In 1873-74, Chapter 2, Original Works. Army- Military, Jabalpur Division. Royal Artillery Barracks and their Subsidiary Buildings, of Annual Progress Report of PWD, Central provinces. Nagpur (1872), W. Ness recommends 'Warora as a suitable locality at which to manufacture iron… Warora will soon be connected by Railway with rest of India; coal and limestone exists in abundance on the spot, and the rich and inexhaustible iron deposits of Lohara and Pipulgaon are not distant…[Estimate of output of iron per ton was based on use of Lime (Rs. 1 for 1/2 ton) versus Kunkur (Rs. 2 for 3.5 tons)]. In 1876, Annual Progress Report of PWD, Central provinces mentions; "All lime for all works has been burned and ground under departmental superintendence and issued to works as required. Nothing but kunkur lime is used and this is used perfectly fresh from the kiln… Now the kunker after being burnt is not slacked until in contact with the sand and soorkee, and the whole ground together in steam mortar mills. I propose to try the use of all coal to burn lime with hereafter, instead of charcoal which is expensive." Burning to produce lime, both kunkar and limestone, with charcoal, and sometimes with cow dung and wood, was slowly replaced with coal. This greatly reduced the burning time.

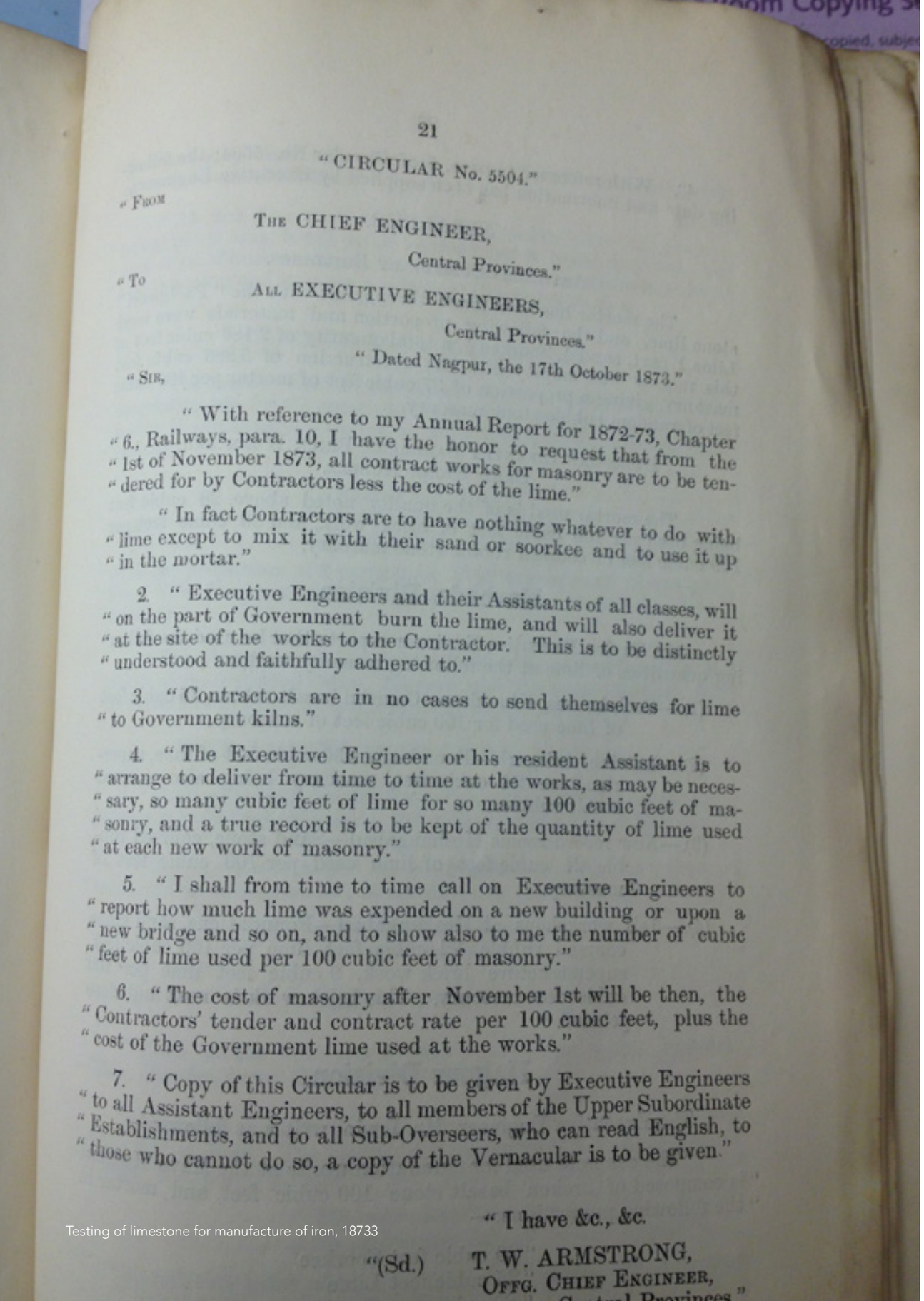
The report continues, for (Workshops, Colliery, Staff quarters) 'some recent trials which were made in this division with mortar during Oct and Nov… results tables appended…one description of lime… fully tested…and this was made from Limestone near Kundalla village about 5 miles to the north of



Map indicating survey by Geological Survey of India, 1854



Map indicating survey by Geological Survey of India, 1872



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"CIRCULAR No. 5504."

"From

THE CHIEF ENGINEER,

Central Provinces."

"To

ALL EXECUTIVE ENGINEERS,

Central Provinces."

"Dated Nagpur, the 17th October 1873."

"SIR,

"With reference to my Annual Report for 1872-73, Chapter "6., Railways, para. 10, I have the honor to request that from the "1st of November 1873, all contract works for masonry are to be tendered for by Contractors less the cost of the lime."

"In fact Contractors are to have nothing whatever to do with "lime except to mix it with their sand or soorkee and to use it up "in the mortar."

2. "Executive Engineers and their Assistants of all classes, will "on the part of Government burn the lime, and will also deliver it "at the site of the works to the Contractor. This is to be distinctly "understood and faithfully adhered to."

3. "Contractors are in no cases to send themselves for lime "to Government kilns."

4. "The Executive Engineer or his resident Assistant is to "arrange to deliver from time to time at the works, as may be necessary, so many cubic feet of lime for so many 100 cubic feet of ma"sonry, and a true record is to be kept of the quantity of lime used "at each new work of masonry."

5. "I shall from time to time call on Executive Engineers to "report how much lime was expended on a new building or upon a "new bridge and so on, and to show also to me the number of cubic "feet of lime used per 100 cubic feet of masonry."

6. "The cost of masonry after November 1st will be then, the "Contractors' tender and contract rate per 100 cubic feet, plus the "cost of the Government lime used at the works."

7. "Copy of this Circular is to be given by Executive Engineers "to all Assistant Engineers, to all members of the Upper Subordinate "Establishments, and to all Sub-Overseers, who can read English, to "those who cannot do so, a copy of the Vernacular is to be given."

"I have &c., &c.

"(Sd.) T. W. ARMSTRONG,
OFFG. CHIEF ENGINEER,
Central Provinces."

Testing of limestone for manufacture of iron, 18733

Warora, a quantity of which was brought here for fluxing purpose in the Iron manufacture experiment and towards which my attention was drawn by the stone burning to a drab colour and not as white as is the case with the stone from the village of Vanjree; I also found it did not slake readily, a feature I know to be common in the burning of hydraulic limes in England.

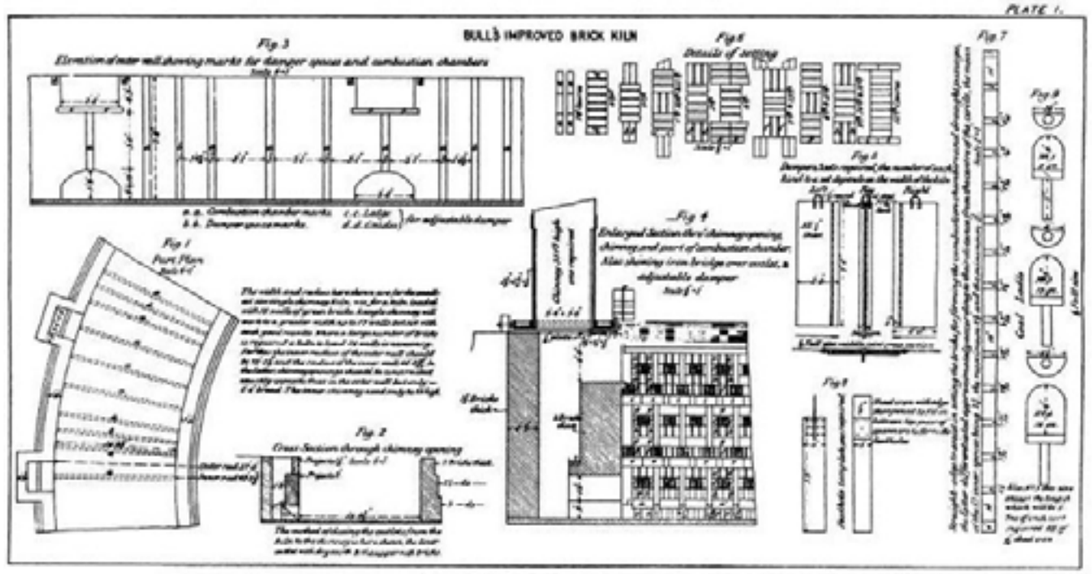
The stone is of dark slate colour containing 88% of carbonate of lime and a little magnesia, the remaining 12 percent being insoluble silicons matter and resembling the mountain limestone common in Britain; when broken into cubes of about 1.5 inch gauge it requires as much fuel to burn it as kunkur, in a katcha kiln as ours is, 100 cubic feet of limestone requires 90 cubic feet of charcoal or 50 cubic feet of coal 'slack,' we have even tried it with 30 cubic feet of slack, in which the daily out-turn of the kiln was much reduced though the stone was all the same properly calcined. The engineer continues to give details of information about burning, slaking, and testing mortar with this lime.

For the next few years engineers in various departments and regions of India continued to work with kunkar lime, stone lime, coal, and charcoal, while trying to improve the quality and reduce the costs of mortar. Based on these above surveys, findings, and experiments, in 1877, The Military Works Handbook was published by the Military Engineering Services, written by Superintending Engineer R. T. Tyndall, for use in Meerut, Agra, Bareilly and Morar but it soon became widely recognised and was used not only in the Military Works Department but also in the Public Works Department. It was regularly updated and new editions were published periodically.

This is a comprehensive book for construction including methods of estimation, specifications, rates and contracts, construction materials and methods complete with detailed drawings for brick kilns, lime kilns, roofing, drains, and masonry bonding among other things. This manual included stone lime, kunkar lime, mud, and cement as binders for mortar. Since most cement was imported during this time, it was sparingly used in flooring and for pointing.

In England, Portland cement was patented in 1824, and was so called from its resemblance to Portland stone.It became common in India only after 1879. A material akin to Portland cement was mentioned by Dr. J. McLeod, Superintendent Surgeon in a letter to the Government of Madras on 11th February, 1826. He wrote: "I have met in bazaars with a species of iron wherein the oxide of iron is exceedingly pure and when calcined nearly the whole was taken up by the magnet. With the proportion of lime I have found the oxide to answer perfectly well when prepared in imitation of Smeaton's Puzzolana cement….My attention was lately directly to another and very different species of cement from any hitherto employed or produced… This valuable mineral exists in abundance and in great purity near Salem. Mr. I. H. Heath caused a specimen to be sent to Mr. Henry of Manchester who has published an excellent analysis of it in the first volume of 'New Series of the Annals of Philosophy'. Having lately had a small building to construct in the interior of which lime was inadmissible, I was induced to make trial of a cement composed of the above magnesia. I found that it set very readily and in five or six days acquired all the properties of a good cement. Another letter dated 21 February, 1826, from the Secretary to Government, Fort St. George, to the President and Members of the Military Board, Madras states: The Hon'ble Governor-in-Council considers it highly desirable that the durability and fitness for general use of the cements prepared from the materials noticed by Mr. McLeod …make experiment…and substituting these for European cements and employing them generally in the public works.

However, cement used as an industrial product in India dates back to 1879, when a European Company named South Indian Industries Limited was established for the purpose in Madras. Actual production could not start before 1904. The factory had a capacity of 10,000 tons annually but owning to several weaknesses of its (a) small size, (b) technical inefficiency, (c) high cost of production etc. it could not continue for long. George Watt's 'Dictionary of the Economic Products of India' published in 1889, contains the significant paragraph" "Portland cement is now made in Calcutta from argillaceous kankar to which a fat limestone is added in the proper relation with the argillaceous constituents. Hitherto this fat limestone has been obtained in Calcutta at a cheap rate as it is brought out as blast. Coconut water and also jaggery is often mixed with lime in making polishing cements in India."



Design of Bull's Brick Kiln, Military Engineering Services Handbook, 1877

In 1914 another company called the Indian Cement Co. Ltd., Porbundar (Kathiawar) again under European management, started manufacturing cement at a large scale. This was followed by Katni and Industrial Limited (Madhya Pradesh) and another Bundi Portland cement Co. Ltd. (Rajasthan). Together they met about a third of India's requirement (0.085 million tons) and the rest was met by heavy import of British Cement…."Report of Sir Huge Keeling, Chief Engineer, Delhi' published in 1918 stated that Bundi and Katni cement….are equal to English brands…the Indian cement industry has… limestone of excellent quality…suitable clay is found close to the works..gypsum and other raw materials… About 1.6 tons of limestone are required to make 1 ton of cement which contains 4% gypsum and uses 38% coal.

According to the reports of the Geological Survey of India, there are large deposits of gypsum in several parts of India….as regards coal, most of the cement factories are at a disadvantage….owning to the concentration of coal in limited areas of Bihar and Bengal….almost half of the total coal required is conveyed from here. The next progressive step was in 1930 with the formation of the Cement Marketing Company of India and amalgamation of smaller units in 1936 to form the Associated Cement Companies Ltd. Many more factories were added in days to come and cement became a common commodity[i].

20th century and the birth of 'Restoration Mortars':

In 1908, the first Annual Report on Architectural Work in India, published by Superintendent Government Printing Press, Calcutta, India was published with an overview of the works done from 1903, in all provinces of India, from the office of the Consulting Architect to the Government of India, set up on 10th December 1902 under James Ransome, within the Public Works Officers in India. The report clearly states that it 'must not trench on the province of the Archeological Department, which was also finally re-started in 1902 under John Marshall. This is the first instance where one sees the parting of ways of 'new buildings' and 'old structures', the first coming under the purview of architects, and the latter under the archeologists[ii]. The 1909-1910 report presents the proposal for a new architectural college in Bombay, by Percy Brown the Principal of the Calcutta Art School. It also reports the publication of a book of designs for various buildings in India by James Rancome. In 1911-12, Consulting Architect J. Begg, makes an interesting note while travelling in India to understand its architecture and technology.

Begg writes that a curious question of the greatest interest 'has been raised by a correspondent in the Times. This gentleman's contention was that the "Indian master builder"…hitherto undiscovered by us, were the most suitable men for Government to employ on the designs of buildings for India…and employed on the buildings of Delhi. He further contends that our policy in India has been such as to tend to the extinction of this race of artists, and insinuates that if we do not produce some of them… (we will) have succeeded in killing out "the master builder".' One can clearly see here the beginning of the debate between the traditional and the modern. As the discussions on the aesthetics continued, buildings continued to be built with the specifications given in the Military Works Handbook as the report in 1910 describes a newly constructed Telegraph Office in Cawnpore (Kanpur), where the 'brickwork has been carried out very successfully, and the "all brick" treatment of the exterior has proved a very successful one for a moderately unpretentious building.' The exposed brickwork of London and England was to become the 'aesthetics' of most early colonial buildings. It continues, 'I approved of a sample of pointing with ordinary Kunkur lime…it may be worthwhile saying…in Indian brickwork…bricks are good and sound…but irregular…and from the point of view of their appearance, is their large gauge…in fact it may be said that the smaller the bricks are in reason the better the effect of the work.'

In the 1914-15 report, Consulting Architect Frank Lishman, writes that completed in 1914 the outer walls of High School in Manipur, 'are of 2nd class work in mud mortar, except exposed faces which are of 1st class brick work in mud mortar. The floors are all of stone and the roofs jack arched over rolled steel joists.' The New Commisioner's Court, Lucknow completed in 1915 was built of '1st class brick in clay, lime plastered inside, and pointed outside. Offices in Allahabad was constructed with 'stone which is from Mirzapur, the external walls being otherwise finished with kutni (stone lime) lime plaster.'The dome on the High Court of Allahabad (1914-15), made of iron encased in concrete, was 'finished with a floating of cement.'

This is the first mention of cement even as use of mud mortar, kunkur lime mortar, and kutni stone lime plaster has been mentioned everywhere. The last report of 1918-1921, describes the construction system of the Purdah School in Lucknow. Built for 'the daughters and sons of Oudh talukadars', was a group of buildings laid out as a 'fine bagh'. Hostel foundations were of first class bricks in lime over concrete. Superstructure is of second class brick in lime up to first floor, and second class brick in clay above, with verandah walls and trimmings of brick in lime. External plaster is of equal parts of Katni lime, Kalpi morung, and Gogra sand. Interior face of walls is finished with kankar lime plaster. This description is very useful as it clearly indicates that up to 1920, mud, clay, kunkar lime, stone lime, and cement were used in the same building depending on its location and importance. With the gradual increase in the production of cement, it's ease of use, and speed of construction, it slowly became the most sought after material of the architects in which to build their 'modern' buildings. However, cement's conflict with lime happened much later with the development of the field of restoration.

In India, the first instance of conservation was noted when Emperor Ashoka ordered to conserve wildlife in the 3rd century BC. Then in the 14th century AD, Firuz Shah Tughlag ordered to protect ancient buildings. Later, during the British Rule, the "Bengal Regulation (XIX)" was passed in 1810, and the "Madras Regulation (VI)" was passed in 1817. These regulations vested the government with the power to intervene whenever the public buildings were under threat of misuse. Then in 1863, Act XX was passed which authorised the government to "prevent injury to and preserve buildings remarkable for their antiquity or for their historical or architectural value. The Archaeological Survey of India (ASI) was established in 1861 to initiate legal provision to protect the historical structures all over India. The Ancient Monuments Preservation Act (VII) was passed in 1904 which provided effective preservation and authority over the monuments, and in 1905 for the first time, 20 historic structures in Delhi were ordered to be protected. Alexander Cunningham became its first Director-General[i].

Restoration work on these monuments gradually started. When in 1902, John Marshall joined as

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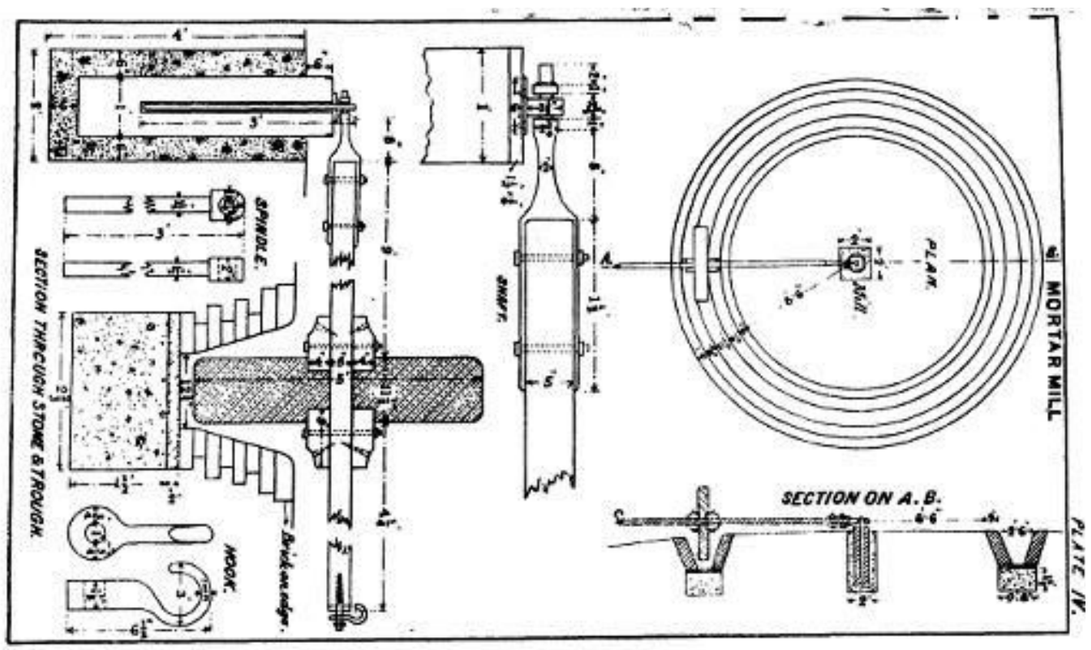
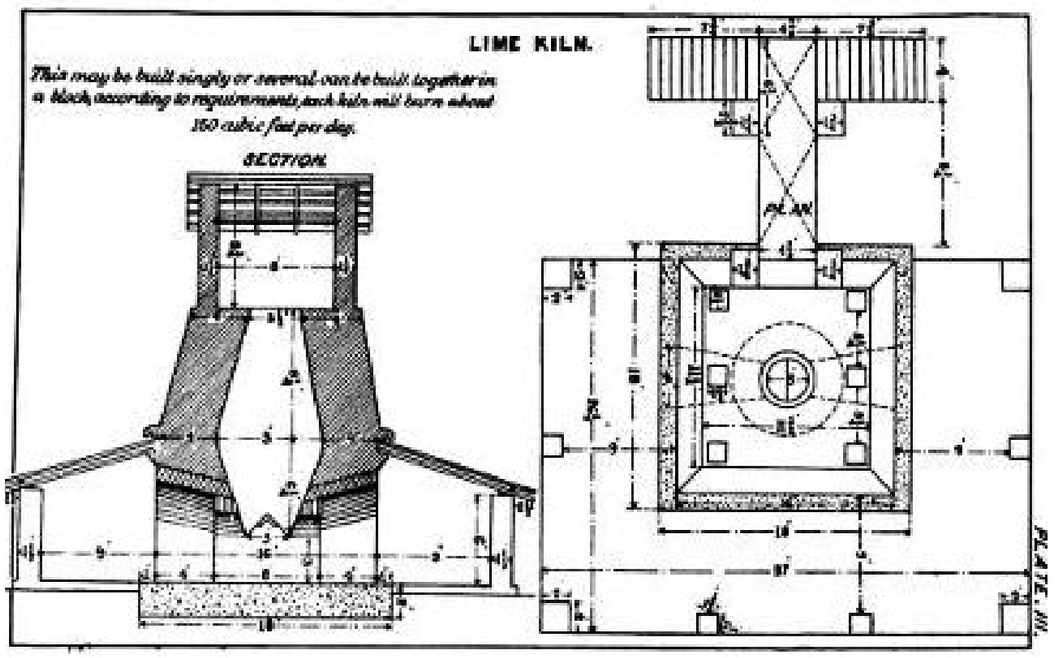
i O. P. Jaggi. Technology in Modern India. (Volume 10). Atman Ram and Sons. Delhi - Lucknow. 1984.

ii Annual Report on Architectural Work in India (1907-1908)

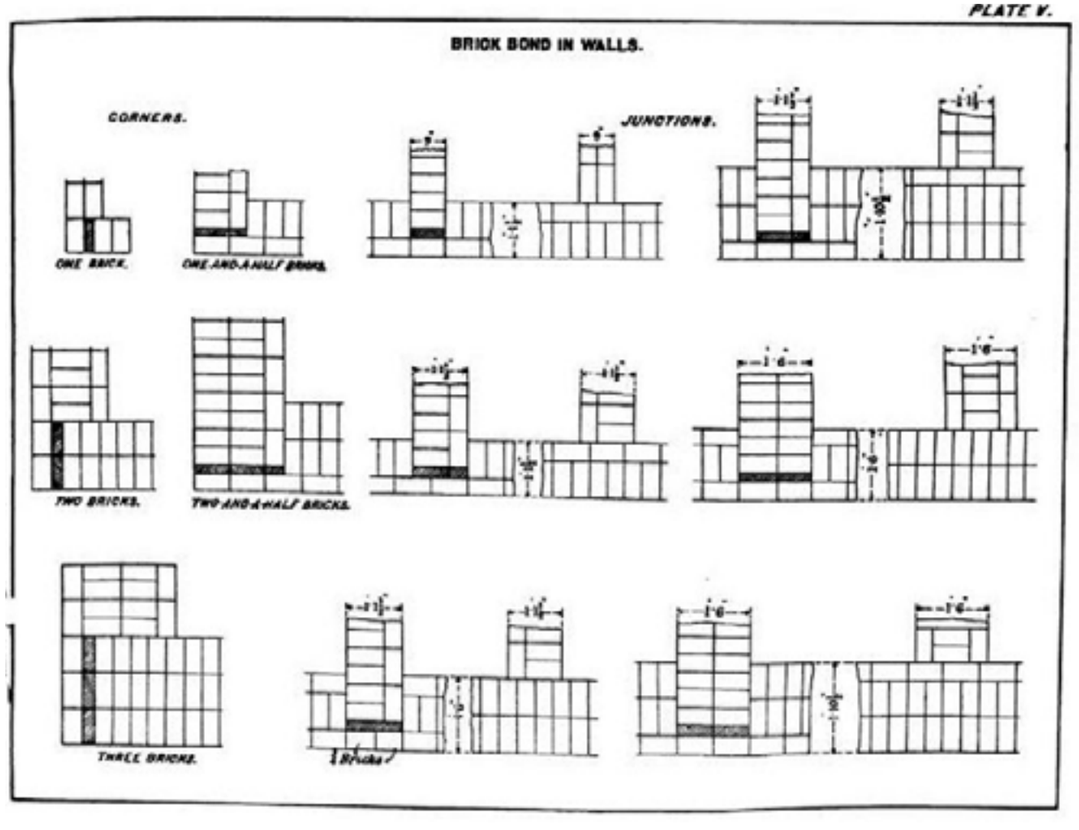
i CPWD & ASI, official website



Design of Mortar Mill, Military Engineering Services Handbook, 1877Services Handbook, 1877


LIME KILN.
This may be built singly or several can be built together in a block according to requirements, each kiln will burn about 350 cubic feet per day.
SECTION
PLAN
PLATE III.

Design of Lime Kiln, Military Engineering Services Handbook, 1877



Brick Bonds, Military Engineering Services Handbook, 1877

Director General and served in the post for a quarter of a century, wrote the Conservation Manual: A Handbook for the Use of Archaeological Officers and Others Entrusted with the Care of Ancient Monuments. Conservation manual by John Marshall was designed to meet the requirements of engineers and builders engaged in new buildings (1923). 'This manual has been divided into two parts. The first part sets forth all essential Government orders regarding the main¬tenance of monuments and the conduct of conservation work, the duties of Archaeological and Public Works officers and their assistants in respect of it, the principles and pro¬cedures to be followed by them, and such other explanations as may have seemed to be requisite. The second part contains detailed instructions and specifications on all questions likely to arise in connection with the conservation of ancient monuments in India.' It gives in details specifications for mud mortar, kunkur lime, stone lime, and cement mortars.

In 1989 this manual was revised, for use in India, commissioned by for INTACH (Indian National Trust for Art and Heritage), by Bernard Feilden, Director Emeritus, ICCROM, a conservation architect, authority in conservation, as part of a UNESCO team based on the principles of the Athens Charter on conservation in 1931, Venice Charter of 1964, and other subsequent charters which were considered influential in the field of conservation. Feilden added and edited many sections but what is useful to note here is his warning about the after effects of cement when used as a restoration material. To the original text of Marshall, Feilden now includes a list of disadvantages if Portland cement is used as a 'restoration material' adding that although Portland cement is a magnificent material for modern structures…it is not designed for use in mortars of plasters of historic buildings. The shift between 'modern' construction mortars and 'restoration' mortars became evident, even as 'restoration' slowly drifted away from mainstream 'construction[i].' The Public Works Department, headed by architects and engineers, well versed in the use of cement technology dealt only with new construction. Whereas the ASI, other archaeologists and historians, were in-charge of restoration with materials other than cement. This is for the first time in the history of construction in India that a difference was made between mortars for construction and mortars for repair and restoration.

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i Bernard Feilden. Guidelines for Conservation. 1989. India INTACH.

Clay mortars being used to rebuild a temple in Patan Durbar Square, Nepal

Chapter 5:

Inferences, Case Studies, and Further Research

This study has been done in three parts. First a chronological and historical study of traditional mortars from secondary sources to assess the variety and non-standard nature of mortars in the Indian sub-continent has been done. Secondly, some local traditions of construction especially those of mortar making to identify traditional and current sources of building materials needed to prepare them have been studied. Great regional variations is found in the sub-continent and in India itself. Craft documentation of the northern alluvial plains has been carried out as an exemplar for this research. Finally, an attempt has been made to develop a methodology for the preparation of restoration mortars in India which addresses the need of variety, quality, and compatibility with the 'original' mortars.

Inferences from Laboratory tests:

Before starting this study many samples were tested (see table). An abundance of clay was found in the laboratory tests of these mortars. Almost all mortar analysis results indicated a high percent of clay in the residue. Further analysis and studies collaborated the findings of the historical research that 'clay' was an integral part of the mortars (and plasters) in India. It has been found in mortars and plasters as a binder, aggregate, pozzolana, and as a useful impurity. While mud, lime (shell, kunkur, stone lime), formed the main binders, sand (river) was sparingly used, brick dust and morung (coarse sand) being used instead. To conclude the laboratory results carried out to understand the presence of clay in mortar samples it is inferred:

Clay as binder: Soil, mud, or clay was extensively used as a binder in mortar for brickwork and stone work. It was also used for flooring and render.

Clay as aggregate and pozzolana: Clay was used un-burnt or burnt to make surkhi to be added to lime as a pozollana, it's excess quantities working as an aggregate. Sometimes surkhi was also used as a binder, with negligible amounts of building lime added as a stabiliser.

Clay as impurity: Kunkur lime, the most commonly used form of building lime had nearly 30% of clay impurities which gave it a hydraulic character, and thus was a good 'cement'. It was (and is) also widely available, for free, and easy to collect, transport, and burn.

Inferences from Historical overview:

New materials added even as old materials continued to be in use: A historical overview of the mortars and plasters in India indicate that as new information came into the country, new technologies were developed, and new materials added to the repertoire of old systems and traditions. So by the end of the 19th century mud, clay, kunkur lime, stone lime, and cement were being used to make mortars and plasters. Traditional systems of construction continued and new ones integrated in the old ones, based on the ease of their use and necessity.

Presented great variety over geographical regions and within building: But this presents to the conservator a great variety, made even more diverse considering the size, geological, and geographical variations within India. So one finds great variations in building materials not only within a single building to make foundations, walls, roofs, and flooring, but also regionally.

No 'restoration mortar as separate from 'building mortar': It is also interesting to note that in the 2000 years of historical overview, no 'repair' or 'restoration' mortars have been mentioned. There are details giving various proportions of mortar to be used as plaster,

LIST OF TESTED MATERIAL SAMPLES
07.12.22

Sno	Acc no.	Place	Site Name / City	Type	Date / Age	Building Type	Remarks			
							Total Weight of Sample	% of Lime by weight	% of Clay by weight	% of Sand by weight
1	WB/BUR/MOR-14/15	Burdwan	Nishiragarh Siva Temple	Mortar	1522	Temple	47	13	36	51
2	WB/BUR/MOR-13/15	Burdwan	Nishiragarh Siva Temple	Mortar	1522	Temple	50	14	11	74
3	WB/BAN/MOR-05/15	Bankura	Mahaprabhu Temple	Mortar	1522	Temple	49	24	29	46
4	WB/BAN/MOR-04/15	Bankura	Mahaprabhu Temple	Mortar	1622	Temple	44	33	18	49
5	WB/MID/MOR-07/15	Midnapore (W)	Gaganeswar Temple	Mortar	1622	Temple	51	3	3	93
6	WB/MID/MOR-08/15	Midnapore (W)	Gaganeswar Temple	Mortar	1622	Temple	52	25	7	68
7	WB/MID/MOR-09/15	Midnapore (W)	Gaganeswar Temple	Mortar	1622	Temple	50	4	19	77
8	ASS/SIV/MOR-02/15	Assam	Ghanshyam House	Mortar	1622	House	20	32	11	57
9	ASS/SIV/MOR-03/15	Assam	Ghanshyam House	Mortar	1622	House	63	27	25	48
10	NEP/PAT/MOR-01/15	Nepal	Krsna Temple	Mortar	1644	Temple	66	36	18	46
11	NEP/PAT/MOR-02/15	Nepal	Krsna Temple	Mortar	1644	Temple	59	16	19	65
12	WB/KOL/MOR-03/15	Kolkata	St. Thomas Church	Mortar	1700	Church	49	12	33	55
13	WB/KOL/MOR-25/15	Kolkata	St. Thomas Church	Mortar	1700	Church	51	22	24	54
14	WB/MID/MOR-11/15	Midnapore (W)	Gaganeswar Temple	Mortar	1722	Temple	52	18	22	60
15	NEP/KAT/MOR-28/18	Nepal	Hanuman Dhoka	Mortar	1801	Public	63	10	19	72
16	WB/KOL/MOR-18/15	Kolkata	Scottish Cemetery	Mortar	1822	Grave	44	23	46	31
17	WB/KOL/MOR-19/15	Kolkata	Scottish Cemetery	Mortar	1822	Grave	72	17	12	70
18	WB/HUG/MOR-16/15	Hooghly	Serampore	Mortar	1822	Public	50	8	42	49
19	WB/KOL/MOR-23/15	Kolkata	Scottish Cemetery	Mortar	1822	Grave	51	20	37	43
20	WB/KOL/MOR-61/18	Kolkata	Currency Building	Mortar	1833	Public	58	11	20	69
21	WB/KOL/MOR-62/18	Kolkata	Currency Building	Mortar	1833	Public	60	10	24	67
22	WB/KOL/MOR-57/18	Kolkata	Metcalf Hall	Mortar	1840	Public	57	10	3	86
23	WB/KOL/MOR-58/18	Kolkata	Metcalf Hall	Mortar	1840	Public	54	4	39	57
24	WB/KOL/MOR-59/18	Kolkata	Metcalf Hall	Mortar	1840	Public	57	15	20	65
25	WB/KOL/MOR-60/18	Kolkata	Metcalf Hall	Mortar	1840	Public	48	10	23	67
26	SC/SWD-6	Kolkata	Scottish Cemetery	Mortar	1845	Grave	47	1	39	60
27	SC/SWG-7	Kolkata	Scottish Cemetery	Mortar	1850	Grave	49	1	56	43
28	SC/SWH-2	Kolkata	Scottish Cemetery	Mortar	1851	Grave	49	2	30	68
29	SC/SWN-12	Kolkata	Scottish Cemetery	Mortar	1862	Grave	49	1	43	56
30	SC/SEN-17	Kolkata	Scottish Cemetery	Mortar	1871	Grave	49	0	24	76
31	SC/SEJ-7	Kolkata	Scottish Cemetery	Mortar	1881	Grave	49	6	16	78
32	SC/SEI-10	Kolkata	Scottish Cemetery	Mortar	1896	Grave	46	5	43	52
33	SC/NEK-9	Kolkata	Scottish Cemetery	Mortar	1903	Grave	48	13	28	58
34	SC/NWL-11	Kolkata	Scottish Cemetery	Mortar	1915	Grave	45	6	41	53
35	SC/NWR-10	Kolkata	Scottish Cemetery	Mortar	1917	Grave	46	12	47	41
36	SC/NED-20	Kolkata	Scottish Cemetery	Mortar	1920	Grave	46	5	33	62
37	WB/KOL/MOR-17/15	Kolkata	North Kolkata	Mortar	1922	Public	49	13	21	66

flooring, render etc., but no mention has been made if a certain type of mortar was used. On the contrary, it was advised to use a 'better quality of the latest material and technology' be used to repair old structures. It is also important to mention that in Indian texts, the word 'mortar' and 'plaster' are used inter-changeably, which has created a mis-understanding, especially in the use of mud or clay mortars. Mud and clay mortars were used extensively till the 19th century as binder for brickwork and stonework. Lime was used for plasterwork.

Inferences from case studies:

Further case studies were carried out to understand the use of the above building materials, i.e. clay, stone lime, kunkur lime, and cement today both in new construction and as 'restoration' mortars.

Mud and clay continue to be used in rural areas, places where the quality of clay is very good, and in hilly regions like Nepal, where high quality clay is available from lakes. Clay is used mostly as a mortar, but it is also used for plaster and as flooring. This is often enforced with straw and other additives. The mud and clay is first processed by simple mechanical means like sieving, soaking, and kneading, before it is is used. Clay is also used liberally in roofs and terraces for insulation. In India mud buildings are not of a permanent nature and need to be maintained annually.

Stone lime from Kutni and Rajasthan areas continue to be the predominant material used in agriculture, road building, as binder in restoration mortar, and for the production of cement. In restoration it is mixed with river sand, coarse morang, and /or surkhi, or brick dust, which acts as both aggregate and pozollana. The same lime is used for whitewashing, stucco, etc. Use of shell lime has become almost extinct.

Some agencies are producing ready mix lime mortars and transporting them to restoration sites. They are also experimenting with fly ash, terracotta and tile powder for use as aggregate and pozollana for use in ready mix mortars used both in new construction and for restoration. Bagged hydraulic limes are also becoming common, which are mostly imported.

Although a lot of kunkar is readily available in areas with old alluvial soils along most of the Gangetic belt, used for making good quality bricks, terracotta sculptures, and ceramic products, it is no longer burnt for making building lime. Researchers like Satish Chandra have given accounts of its burning and use, but we could not find any lime kilns or people who were aware of kunkar lime or its use as building lime.

Search for a solution:

To understand and effectively restore we need to document as many mortars and renders (plasters) as possible from as many regions and situations as possible. These samples need to be tested to understand their nature and use in the specific solution before preparation of restoration mortar. One needs to move away from the concept of 'standard' restoration methods and materials. Historical survey indicates that 'new methods and materials' were not harmful for repair and restoration. Updated technology and materials, used efficiently and effectively, can make good 'restoration mortars'. We need to develop as scientific system for developing 'bespoke', non-standard, restoration mortars from available materials and technology. The next section looks for some solutions to the above problems.

Case Study 1 :

Use of Clay and mud mortars in Nepal

Many types of clay are available in Nepal from nearby lakes. Thus clay is abundantly used for making high quality bricks, tiles, and is even used as mortar, plaster, and flooring. The use of clay continues to the present day. Unfortunately, most of the restoration work on these buildings constructed with clay has been done with lime not only leaving an unaesthetic surface but also damaged the original fabric. If a stronger material like cement can damage a building built with lime mortar, a building built with clay mortar is damaged by lime mortar.

Traditional construction system in Nepal

Restoration of a heritage building

Use of clay for mortars and plasters

Case Study 2 :

Mud Houses in Purulia, Bihar, India

Mud, clay, and other locally available material in combination with bricks and tiles, both baked and unbaked, are commonly used all over India for construction in rural parts of India. These materials differ and are area specific to the region but all continue the use of clay or mud. Purulia is a village in east India famous for its colourful mud houses. The houses are painted every year before the festival season. They are made from local mud, bamboo, and covered with terracotta tiles. Clay and mud is often mixed with straw and cow dung as needed. The flooring and plaster is also made of clay and the large overhanging roofs protect these mud walls from getting wet and loosing their strength. These houses however, need regular annual repair.

Wall painting on a house in Purulia

Bamboo used to support the roof

Mud plaster

A broken house exposes the mud construction

Case Study 3:

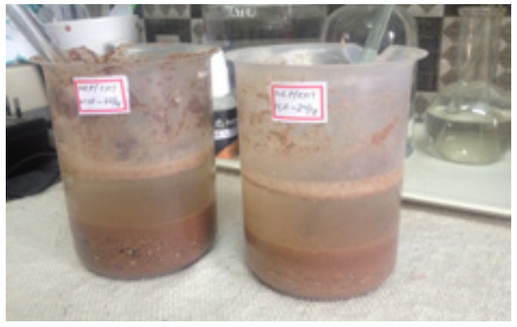
Use of Stone Lime and Surkhi in Mortars

Mortar Analysis, field study, and literature study have indicated that stone lime and surkhi (brick powder) are the commonly used materials for the preparation of the restoration mortar after the 20th century CE. Lime is often sourced as burnt stone or in powder form and mixed in a traditional or modern 'chakki' with sand, surkhi, and water. The surkhi, traditionally prepared by burning clay, is now prepared mostly by grinding bricks. Surkhi in this form is both used as an aggregate and if fine, acts as a pozzolanic material, and helps in quick set of the mortar. When tested, surkhi displays all properties of clay.

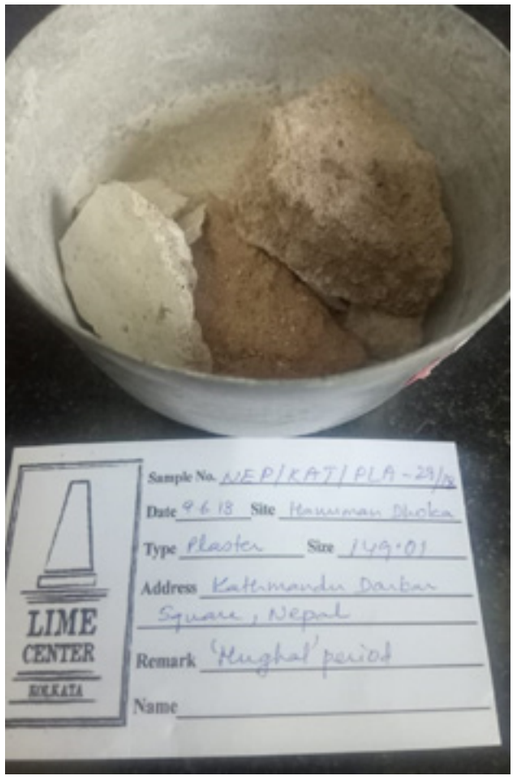
Traditional surkhi plaster

Heritage building in lime and surkhi

Surkhi being served on site



Testing of surkhi in a lab



Mortar sample

Mortar mixer or 'chakki'

Case Study 4:

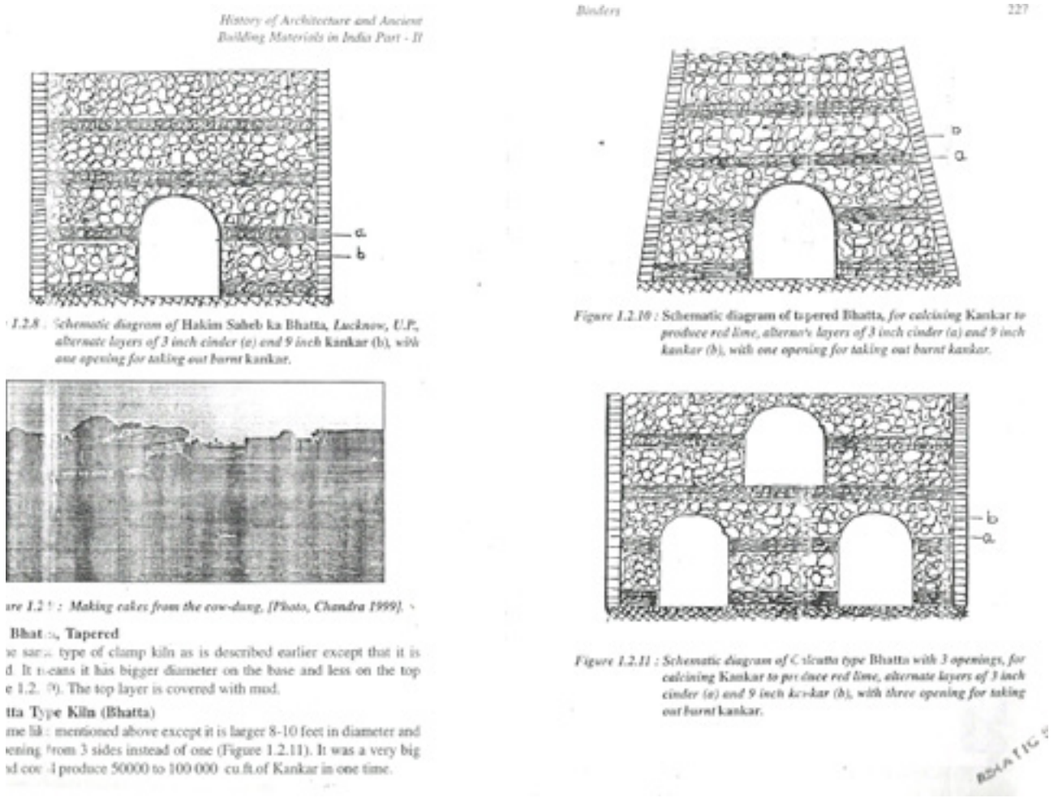
Lime in the Gangetic old Alluvial Plains, Kanpur & Lucknow

Among other local materials used for the construction of buildings up to the 20th century was kunkur lime, sometimes referred to red lime. Having a high percent of clay, it is a good building lime, and was used extensively till stone lime, mined for the preparation of iron, and later cement, replaced it completely. It is abundantly found in the Gangetic and old alluvial plains of north India. The soil in these areas is not very fertile, has a sparse vegetation, and not considered good for settlements. Areas such as these, and the lime nodules on them, kunkar, lie wasted. The technology that was used to burn them is also extinct. Mortar analysis of samples prepared with kukkar lime show high quantities of clay in the aggregate.

Kunkur lime nodules in the field

Kunkur lime nodules in the lab

A kunkar lime wasteland in SGPGI, Lucknow


History of Architecture and Ancient
Building Materials in India Part - II
a
b
1.2.8 : Schematic diagram of Hakim Saheb ka Bhatta, Lucknow, U.P., alternate layers of 3 inch cinder (a) and 9 inch kankar (b), with one opening for taking out burnt kankar.
ure 1.2 : Making cakes from the cow-dung, [Photo, Chandra 1999].
Bhat , Tapered
e sar type of clamp kiln as is described earlier except that it is
d. It means it has bigger diameter on the base and less on the top
e 1.2. (9). The top layer is covered with mud.
tta Type Kiln (Bhatta)
me lik mentioned above except it is larger 8-10 feet in diameter and
ening from 3 sides instead of one (Figure 1.2.11). It was a very big
d can produce 50000 to 100 000 cu.ft.of Kankar in one time.
Binders
227
a
b
Figure 1.2.10 : Schematic diagram of tapered Bhatta, for calcining Kankar to produce red lime, alternate layers of 3 inch cinder (a) and 9 inch kankar (b), with one opening for taking out burnt kankar.
b
a
Figure 1.2.11 : Schematic diagram of Calcutta type Bhatta with 3 openings, for calcining Kankar to produce red lime, alternate layers of 3 inch cinder (a) and 9 inch kankar (b), with three opening for taking out burnt kankar.

Sketches of kilns used for burning kunkur lime

Such areas are used for mining clay for bricks, Lucknow

Case Study 5:

Development of New Restoration Materials, Ahmedabad

Many new products are coming in the market which are recycled or promote sustainable methods of construction. Keyur Patel in Ahmedabad runs such an organisation where the old used tiles, bricks, slag etc. is collected and then ground together to make a clay like aggregate for construction. They also manufacture ready mix lime mortars prepared from such aggregates to be used for restoration sites.

View of the factory

Preparation of fine pozollana

Stacked waste tiles for recycling

Keyur bhai explaining the raw materials used by them

Demonstration of traditional mortar by a mason

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18th century brickwork from barracks in Kanpur

Machinery used to grind the recycled material

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